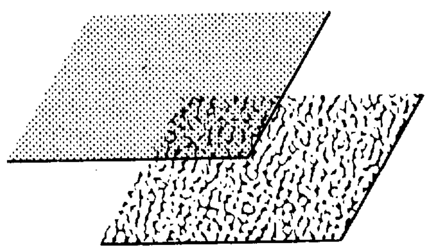
final report

Development of an Evaluation Model

CHANGE DETECTOR



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FOREWORD

This report covers work performed by the [redacted] on the development of a Change Detector Evaluation Model. The program began in July 1962 and was concluded in April 1965. Chief contributors on this program were: [redacted] Project Engineer; [redacted]

[redacted]

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SECTION I - INTRODUCTION

1. PURPOSE

[redacted] has conducted a development program to design and fabricate an evaluation model of a change detector which will compare two sets of imagery taken of the same geographic area at different times and will display and locate any changes that occurred between the times that the imagery was obtained.

2. SCOPE

The program consisted of four tasks designed to proceed through a logical development program to the completion of the evaluation model:

1. System predesign,
2. Display data processing studies,
3. System design,
4. Checkout and evaluation.

The system predesign phase of the program consisted of a definition of the system configuration, a selection of some of the critical components of the system, and an up-dating of the breadboard system. The display data processing studies phase consisted of developing techniques for minimizing the effects of unwanted changes, such as shadows and clouds, when desired. Methods of enhancing changes were also developed. The system design task involved the design and fabrication of the complete system. The checkout and evaluation phase of the program included a "debugging" of the system and evaluation of the various functions.

SECTION II - SYSTEM DESCRIPTION

1. GENERAL

The change detector is a device that will manually or automatically register two photographic images and display any differences or changes between the two photographs. Figure 1 shows a simplified system block diagram of the change detector.

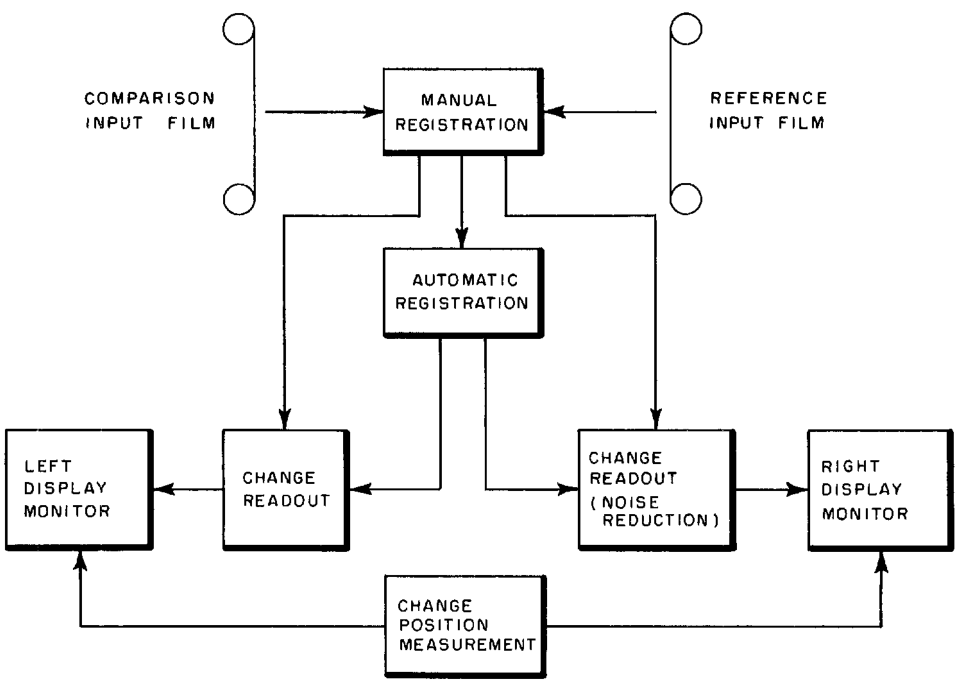

Figure 1. Change Detector, Simplified System Block Diagram

After insertion of the two films, and an identification of the areas of comparative coverage a manual alignment of the two film images must be accomplished to obtain a coarse registration. Once this coarse registration is obtained, the display system may be activated to view gross changes requiring less registration accuracy or the automatic registration system may be activated to obtain the fine degree of alignment required to detect changes of a higher order of resolution. Upon completion of the registration process the changes or difference between the two photographs are displayed on two display monitors. Various techniques for change enhancement and minimization of unwanted changes are available when desired. Position readouts of the observed changes can then be accomplished.

2. MANUAL REGISTRATION

Registration of two photographic images may require up to six degrees of freedom. Translational displacement (X and Y) of one image relative to the other is necessary since it is unlikely that the center of the two photographs will have an identical geographic location. The rotation of one image relative to the other is necessary to compensate for differences in azimuth. The magnification of one image relative to the other must be adjustable to compensate for differences in scale factor due to variations in camera focal lengths and altitude. Unless highly stabilized camera mounts were employed to obtain the imagery, tip and tilt corrections are also necessary to complete the registration process.

These six degrees of registration freedom are available in the manual registration controls. With an image of each photograph displayed on its respective monitor, a manual alignment of the azimuth difference of the two photographs should be accomplished first since this is the most easily recognized registration error. The translational corrections and scale factor alignment should then be performed. If the tip and tilt errors are known, their corrections can also be inserted at this time. If only a coarse registration is desired, the change detection function can be activated and the changes observed on the monitor displays. When a finer degree of registration is desired the automatic registration system should be activated.

3. AUTOMATIC REGISTRATION

With the activation of the automatic registration system, the scanning displays are made inoperable and an area correlation of the two photographs is performed automatically. A backlight is activated behind one of the films and the resultant scene is imaged on the other film. The light transmitted through the second film is a measure of the correlation of the two films and is focused on a phototube which generates the electronic correlation signals. If both films are of the same polarity, i.e. both positives or both negatives, a maximum of transmitted light will result when the two films are perfectly correlated. The sequence of operations to obtain an automatic registration of the two films is as follows: an X and Y search and lock-on is performed to get within the dynamic lock-on range of the correlation function; the dynamic lock-on or nutation system is activated and the X and Y displacement errors are eliminated by a translation of the X,Y registration mechanism which moves the image of one film across the other until the error signal is at null. Similarly, azimuth and scale factor errors are eliminated by sensing the errors generated by the nutation process and driving the azimuth and scale factor correction mechanisms until the error signals are nulled.

4. READOUT

Upon completion of the automatic registration function the system is programmed to proceed automatically to the readout mode. The following methods for change detection are available in the system:

1. Side-by-side comparison - each film image displayed on a monitor.
2. Flicker change detection - each film image alternately displayed on a single monitor at a low frequency rate.
3. Video difference change detection - a subtraction of the two film images, either right minus left or left minus right.
4. Video difference cloud and shadow rejection - the video difference technique with added circuitry to minimize the effect of undesirable shadow and cloud changes on the change display.
5. Video difference change enhance - a rapid method for determining the existence of changes by displaying all changes in one polarity (white) against a background which may be completely blanked out when desired.

In addition, to fully utilize the resolution capability of the system an area of interest may be selected and a blow-up of the area made for a detailed inspection. Cross-hairs located at each film plane enable the operator to locate the areas of interest. Readout indicators which correspond to the cross-hair positions permit position recording of the areas of interest.

5. PROGRAM DESIGN GOALS

With the initiation of the program to develop and fabricate a change detection system, a list of program design goals was generated. Some of the original design goals were modified to meet new requirements imposed on the system. Table I shows the design goals finally employed.

TABLE I - CHANGE DETECTOR DESIGN GOALS

Characteristic	Value
Film Input	70-mm roll film, 250 ft max
Film Motion	Continuous slew - .02 to .2 in/sec and 2.4 to 24 in/sec
Image Registration	
Translation (X and Y)	± 50 percent of full scale
Orientation	± 180 degrees
Scale Factor	2X
Scene Magnification	
Film to Display	5X
Area Blow-Up	40X
Output	2-14 inch TV displays
Position readout accuracy with respect to film frame	± 5 percent of full scale
Operation Time	
Initial Set-Up	2 min for first frame
Subsequent comparative coverage frames	30 seconds per frame
Scene Resolution	50 line pairs per millimeter at maximum area blow-up

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SECTION III - SYSTEM DEVELOPMENT

1. GENERAL

The program was divided into four major phases which are: system predesign, display data processing studies, system design, and system checkout and evaluation. The system predesign phase consisted of the following tasks: a definition of the basic system configuration which would meet the design goals, a selection of some of the critical components needed in the system, and a modification of the existing change detector breadboard to increase its performance capabilities. The display data processing studies phase involved the development of the video readout circuitry for the system. It included a study of methods of eliminating shadow and cloud differences from the change display. Methods of enhancing the changes and flicker techniques were also developed. The system design phase included the development and fabrication of the electronic and mechanical components and assemblies as well as the console cabinet of the system. The checkout and evaluation phase began after the entire system was assembled.

2. SYSTEM PREDESIGN

a. Definition of System Configuration

(1) Manual Registration. It became increasingly apparent during the initial phase of the program that to use individual position servos to obtain manual adjustment in X, Y, scale factor and azimuth; to perform automatic registration in these four axes; and to perform the correlation mask function would result in a prohibitively large

number of these servos. An implementation has been developed which minimizes the number of servos required. It consists of tying the optical elements in the two channels of the system to two rigid rods which are held at pivot points at one end and control mechanisms at the other. The rods are shown in the simplified schematic of the manual registration system in Figure 2. For manual registration in X and Y, a translation of the right rod control mechanism results in a translation of the rod and eventual translation of the image of the right film displayed on the monitor. Similarly, a translation of the left rod control mechanism results in a translation of the left film image displayed on the monitor. Azimuth corrections are applied by a rotation of the dove mirror system. The dove mirror system was chosen for azimuth variations because it can be rotated about the center line of the optical axis without any X or Y translation of the image as would be the case if the film were rotated. The dove mirror system is tied to the rod and moves with it. Scale factor variation is accomplished symmetrically in both channels by axial movement of the lens holding assemblies along the rods. Axial position information from the lens holding assemblies is fed to the two film magazine assemblies to provide the movement necessary to maintain focus of the images as the scale factor is changed.

An approximate correction for tip and tilt errors in the imagery is accomplished by an angular variation of the film magazines about the center of the film planes in both a vertical and horizontal direction. Tip correction is applied to the left film magazine and tilt correction to the right.

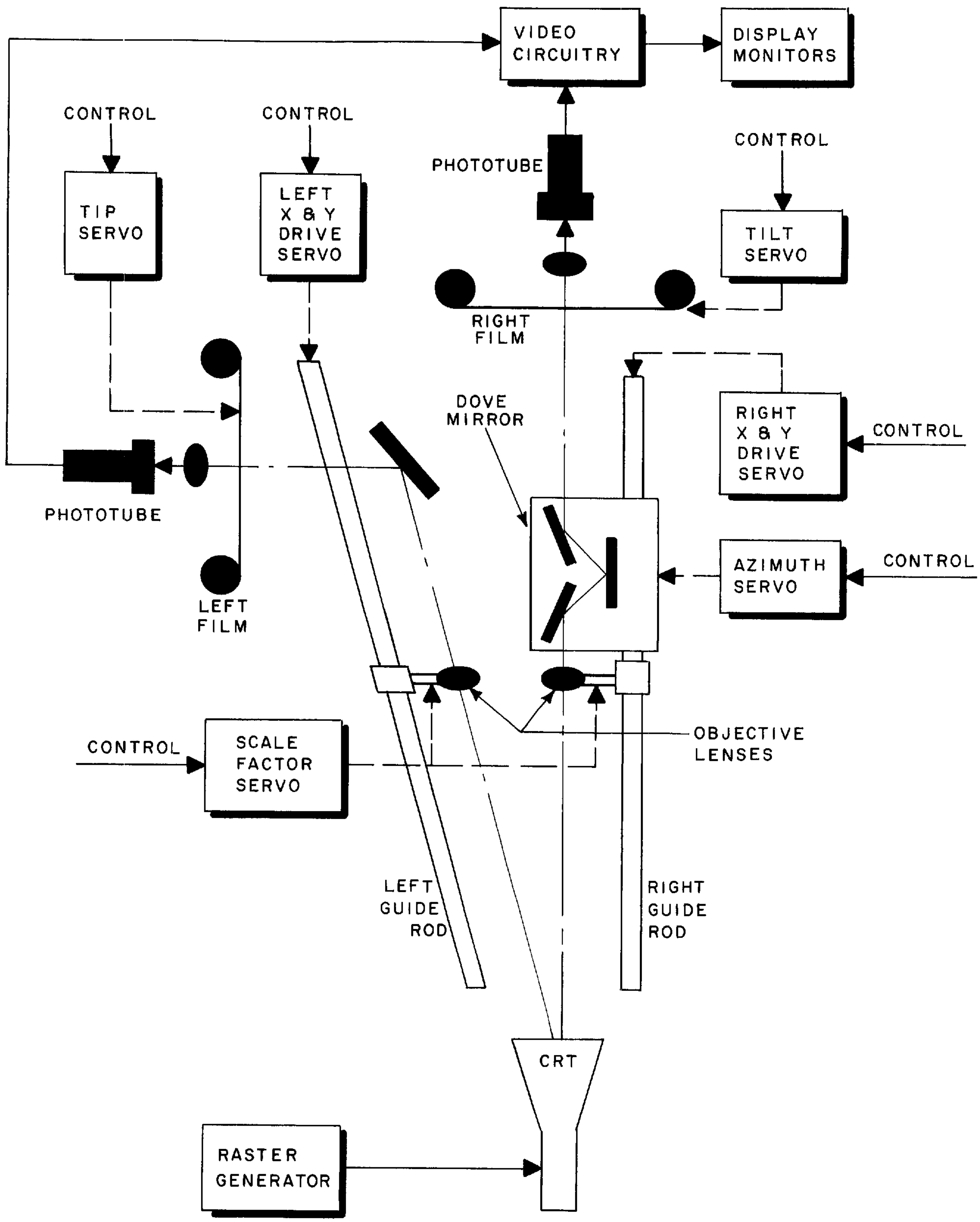

Figure 2. Simplified Manual Registration, Block Diagram

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All of the controls for these six degrees of registration freedom are located on the front control panel.

(2) Automatic Registration. Upon completion of a manual registration of the two films the automatic registration function of the system can be activated when a finer degree of registration is desired. Figure 3 shows a simplified block diagram of the registration system including the automatic registration components. Since the automatic registration of the two films is based on an area correlation, the scanning CRT light source is removed from the optical system by insertion of the movable mirror, and the right phototube is replaced by the backlight. The light paths are as shown in the block diagram. The first phase of the automatic registration procedure is the X and Y search and lock-on. In the search mode, the image of the right film is moved across the left film in a raster search pattern. This raster search pattern is generated by a movement of the comparison lens drive mechanism. The left photomultiplier tube senses the changes in light as the search takes place and converts them to electronic signals which are fed to the match point detector and coordinate storage circuitry. This circuitry takes the second derivative of the match signal from the photomultiplier and stores its highest value during search. The coordinate storage circuitry senses the X and Y position of the lens during the search and stores these coordinates at the match point. The second derivative of the correlation signal is used because it eliminates match point errors caused by bias changes such as shading across the photographs. Once the match point has been determined,

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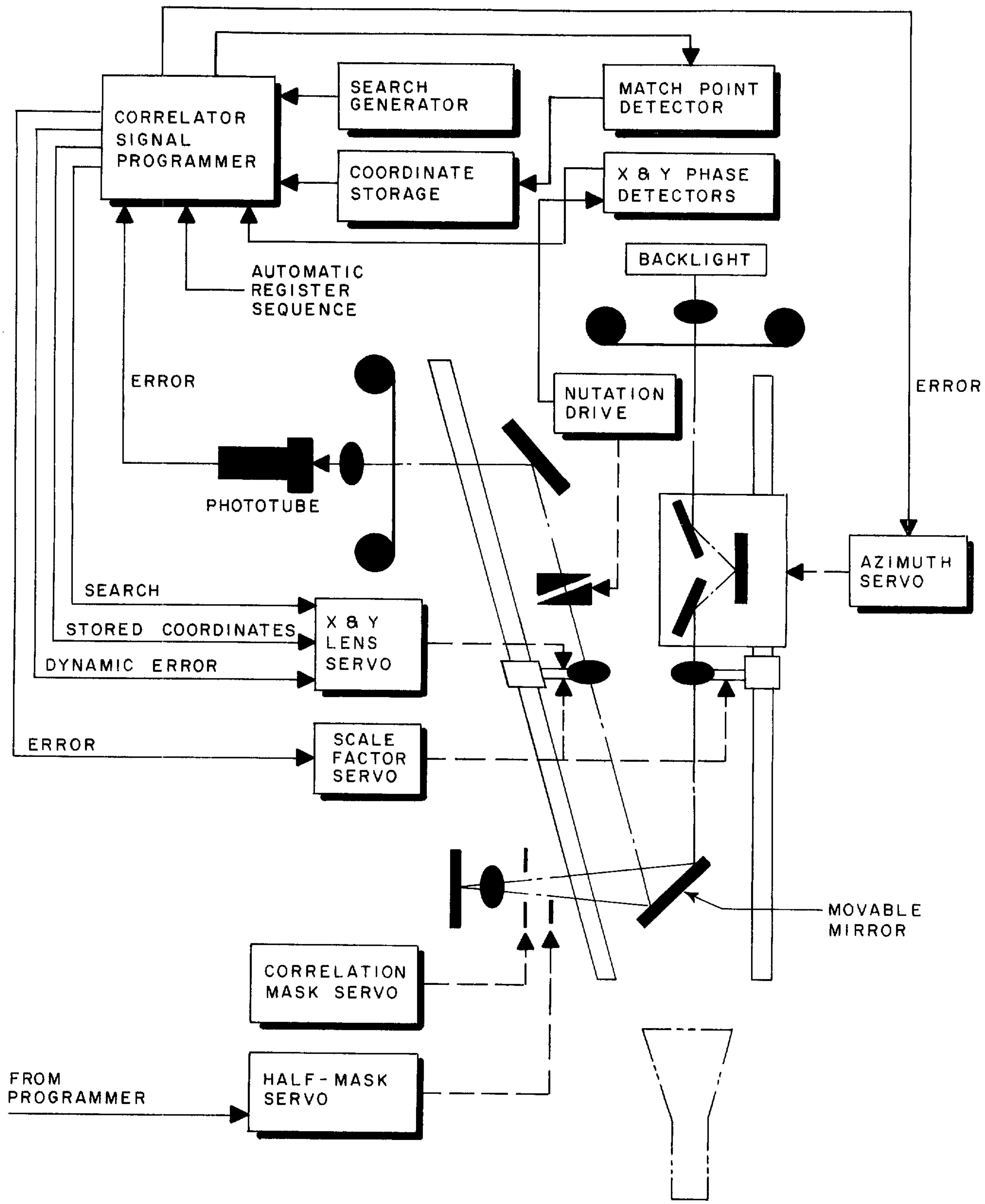

Figure 3. Automatic Registration, Simplified Block Diagram

the lens drive mechanism is returned to the coordinates of the match point. During the automatic registration process only the areas of comparative coverage can be correlated. Also, the area of the right film image correlated must be smaller than the left film to avoid over-scanning during search since the edge effects caused by improper masking can unbalance the registration. The correlation mask located in front of the image reflecting surface provides this capability. The size of the correlation mask is dependent on the amount of overlapping area in the two photographs. Information to control the size of the mask is fed to the mask from the X and Y rod control servos during the manual alignment operation.

Following the search and lock-on phase of the automatic registration small translational, azimuth, and scale factor errors exist in the registration. The nutation wedges are energized, resulting in a circular nutation of the right film image projected on the left film. The error signal generated is then phase discriminated to resolve the X and Y error components. These X and Y error components are fed back to the comparison lens drive servo to reduce the error to zero. The comparison lens drive is then locked in position and the half-mask is inserted in front of the correlation mask so that only the right half of the right film image is projected on the left film. With the nutator running, an azimuth error in the area now being correlated will show up in the Y channel phase discriminator since the X components of the error signal generated by the circular nutation of the targets above and below the center of the new correlation area cancel. Similarly, a scale factor error between the two films shows up in the X phase discriminator since targets above and below the center of the correlation area generate equal and opposite error signals which cancel in the Y channel. The Y error signal is fed to the dove mirror azimuth servo to null the rotational error, and the X error signal is fed to the scale factor servo to null the scale factor error. With the nulling of azimuth and scale factor errors accomplished, a smaller X and Y translational error is introduced. The azimuth and scale factor assemblies are then locked in position, the half-mask removed, and the output of the X and Y phase discriminators returned to the left lens drive for correction of the translational errors. When registered in X and Y the same process is again repeated for scale factor and azimuth. In all, three complete operations of this registration process are required to obtain the desired accuracy of registration. The advantage of this iterative method is that only one nutation mechanism is required for dynamic registration of the two films in X, Y scale factor and azimuth. The time required to complete three matching cycles is still less than that required to perform simultaneous nutation in all four axes since nutation in scale factor and azimuth would require movement of large mechanisms resulting in a prohibitively low frequency of nutation.

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(3) Readout. Upon completion of registration of the two films, the movable mirror is placed out of the optical path, the backlight is replaced by the right phototube, and the scanning CRT is activated. Since both films are scanned simultaneously from the

scanning CRT light source, the video outputs from each phototube may be amplified and displayed on each monitor for a side-by-side comparison, or the video outputs may be subtracted to form a difference display on one of the monitors. The video outputs may also be displayed alternately on the left monitor at a low frequency rate to provide flicker change detection. In addition, video rejection and clipping techniques applied to the video signals result in the minimization of undesired changes such as shadows and clouds and the enhancement of desired changes in the difference display. The size of the raster on the scanning CRT can be reduced to cover a smaller area on the two films. Since the size of the raster on the readout monitors remains constant a blow-up of the scanned area results on the monitors. By keeping the number of raster lines constant while varying the sweep amplitude, an increase in the readout resoltion is achieved when the raster size is decreased. The scanning raster may be moved to any position on the CRT in order to examine any part of the photographs in detail.

Cross-hairs located at each film plane provide the capability to locate changes or other areas of interest on either film. Position readouts and control of each cross-hair are available on the control panel. Position may be measured with respect to a fiducial mark or any other reference point within the film aperture.

b. Selection of Critical Components

(1) <u>Lens Considerations.</u> One of the first selections required in the system predesign was that of the objective lenses which would meet the resolution, distortion and shading requirements of the system.

[redacted]

Since no specifications on commercially available lenses were available for the off-axis application requirement of the system at the wavelength of light emitted by the CRT phosphor, it was decided that several types of lenses would be evaluated in the breadboard change detector. The lenses were tested by scanning identical test targets in each channel of the breadboard and taking the difference between the two video outputs. Any distortion or shading in the lenses showed up as a difference or change in the resulting video output. Two types of the lenses tested, the [redacted] f/5.6, 190-mm enlarging lens and the [redacted] 9-1/2 in f/6.8 enlarging lens, showed distortion and shading characteristics compatible with the system requirements. The resolution capability of both lenses was found to be above the 50 line per millimeter system design goal. The addition of the dove mirror assembly to the system necessitated a longer focal length due to its length. The 9-1/2 inch [redacted] lens was therefore chosen.

(2) <u>Phototube Investigation.</u> A study was conducted to select a photomultiplier tube which would best meet the system requirements. When used in the registration mode the signal-to-noise requirements of the phototube are not severe due to the narrow signal bandwidth involved. The readout mode and its associated wide signal bandwidth, however, requires a phototube with good noise properties. Linearity of the output signal for variations of input light intensity is also important especially in the video difference readout mode. Two phototubes [redacted] exhibited a signal-to-noise ratio of better than 20 to 1 when checked in the

[redacted]

system by scanning a black and white bar pattern with the CRT light source. This signal-to-noise ratio was acceptable for use in the system. Non-linearity of the phototube was determined to be negligible. Since the two tubes were of equal quality in performance the 6199 was chosen because of its smaller size.

(3) Cathode Ray Tube Choice. The spot diameter of the scanning CRT determines the ultimate readout resolution of the system since the remainder of the components have a higher inherent resolution capability. The original resolution specification of 20 line pairs per millimeter required a tube having a spot diameter of .0015 inches or better. A [redacted] 5-inch CRT which has a .001 inch spot diameter was chosen. This tube demonstrated a resolution capability of 30 line pairs per millimeter when scanning a standard USAF test target. When the resolution design goal was changed from 20 to 50 line pairs per millimeter a .0006 inch spot diameter requirement was placed on the scanning CRT (assuming negligible resolution loss through the system optics). A [redacted] was selected for evaluation in the breadboard system. This tube did exhibit the required spot diameter, however the light output from the [redacted] phosphor was too low for use in the system. A [redacted] was eventually selected as the best compromise. A spot diameter of approximately .0008 in. is obtainable in this tube when using the maximum available system high voltage of 17.5 kilovolts. A beam current capability of over 30 microamperes which results in light output compatible with the system requirements dictated the choice of this tube. The selection of the [redacted] re-

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quired modifications to the CRT focus circuitry since this tube requires magnetic focus, whereas the tubes previously employed required electrostatic focus.

(4) Display Monitors. The two 14-inch television monitors selected for the system readout displays are [redacted] professional monitors. These studio quality monitors employ circuitry capable of displaying all the resolution supplied to them in the video signal. They have regulated high voltage and low voltage power supplies capable of delivering a stable display free of jitter or jumping under conditions of varying line voltage. All controls for set-up and operation are available on the front panels of the monitors.

c. Modification of Breadboard Change Detector

One of the tasks of the system predesign phase was a general updating and modification of the existing breadboard change detector for use in the display data processing studies phase of the program and for checkout of improved system components. The general updating of the system included the development of a synchronizer capable of delivering the necessary waveforms to generate a fully interlaced 525 line raster on the CRT and display monitor. A method of varying the size of the CRT raster to achieve an area blow-up of the display was developed for the breadboard. An improved video amplifier and video difference amplifier with a bandwidth of greater than 4 megacycles was developed for use in resolution measurements and checkout of other video system components. The [redacted] lenses were installed and

[redacted]

evaluated in the breadboard. It was also used to evaluate the dove mirror concept of azimuth variations. In addition, all components and circuitry connected with the readout and display portion of the final system were installed and evaluated in the breadboard change detector prior to installation in the console.

d. Breadboard Correlator

During the initial phase of the program a breadboard correlator was developed which is shown in Figure 4. This breadboard was

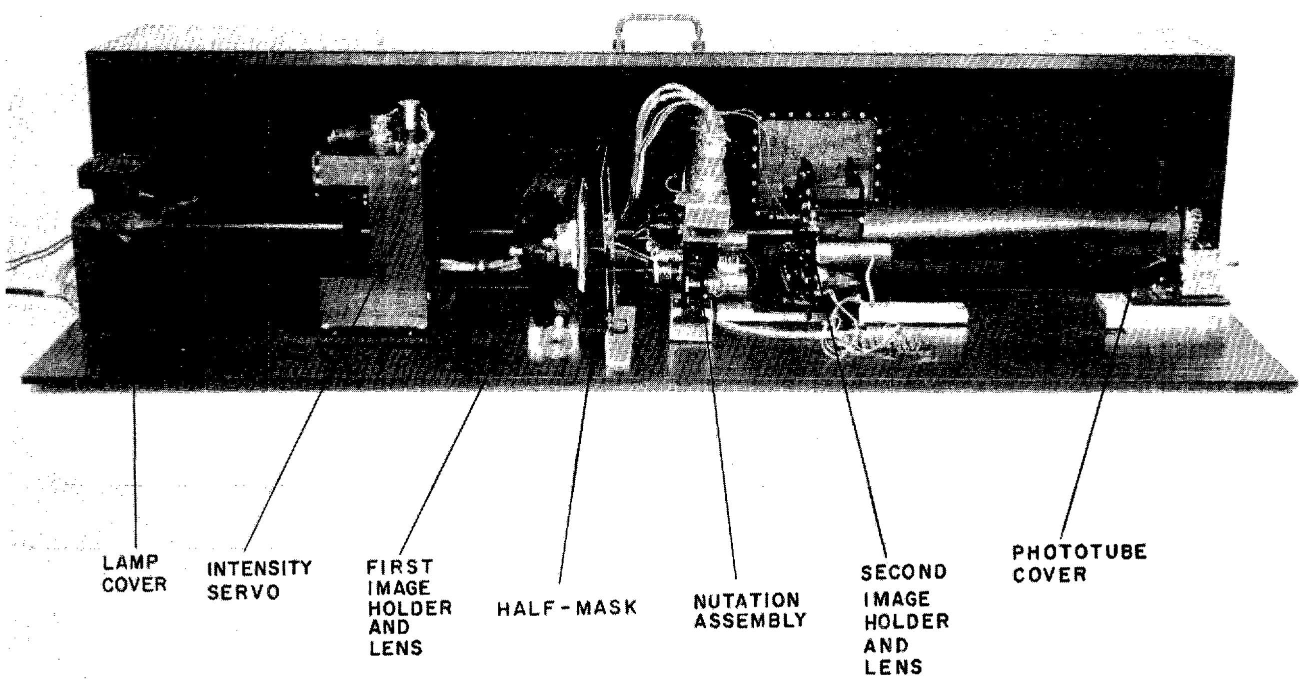

Figure 4. Correlator Breadboard

developed primarily to checkout the half-mask concept for registering azimuth and scale factor errors. The breadboard consisted of a backlit scene, a correlation mask and half-mask assembly, a nutator, X, Y lens servo, and a second scene mounted in a rotating assembly used as an azimuth servo. It was determined that satisfactory registration in X, Y and azimuth could be achieved by using a minimum of three iterations. No scale factor registration was attempted in the breadboard, however, scale factor correlation curves were generated by moving the lens system axially within the depth of focus. In addition, considerable insight into the problem of programming the various automatic registration functions was gained from the breadboard correlator.

3. DISPLAY DATA PROCESSING

a. Video Readout System

The original intent of the display data processing studies was to investigate techniques for elimination of insignificant or unwanted changes from the change display and to develop methods of enhancing the change output for more rapid detection of significant changes. However, when development of circuitry to provide these capabilities was begun it was determined that the entire video readout system development must be considered due to the integral relationship of the circuitry. A block diagram of the video readout system is shown in Figure 5. With the CRT light source scanning each film in synchronism both phototubes sense the changes in light and convert this light into video signals which are proportional to the changes in transmissivity of the films. Video pre-amplifiers in each channel which are located adjacent to their respective phototubes provide isolation for the phototubes and drive the coaxial cables feeding the video amplifier located beneath the con-

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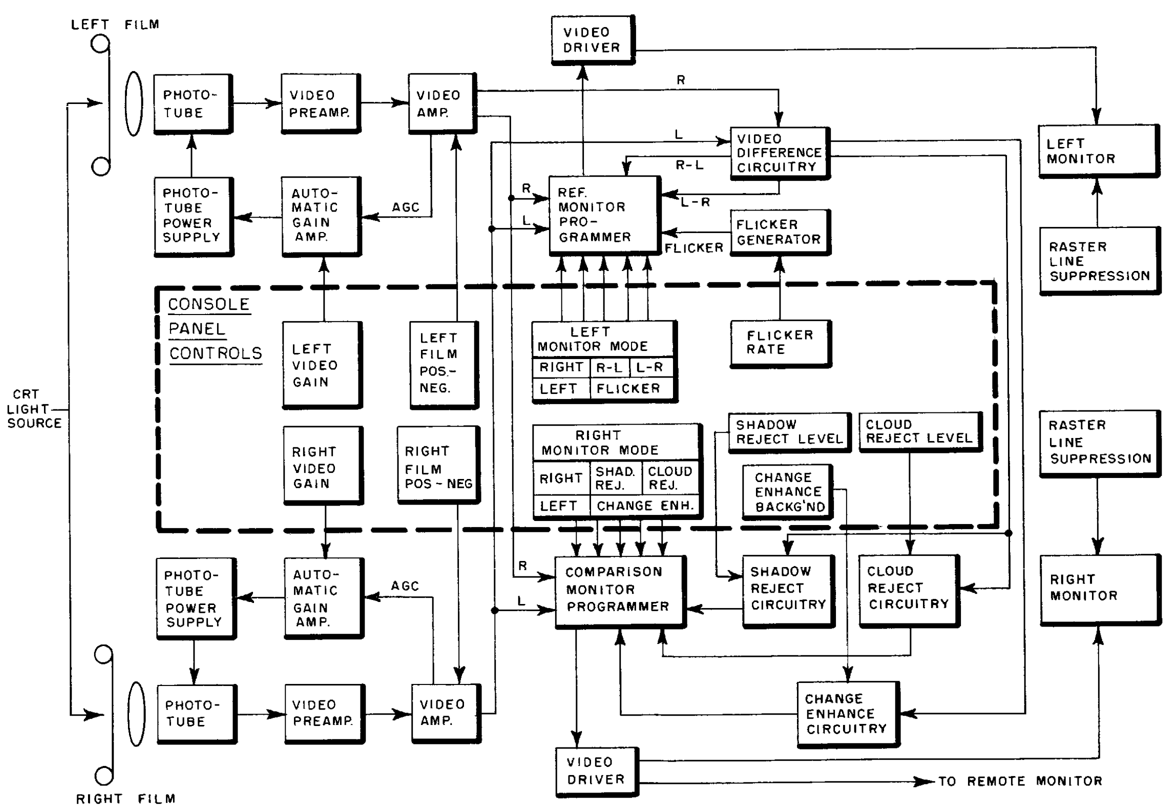

Figure 5. Video Readout System

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sole control panel. The video amplifiers provide the necessary gain to bring the video level up to approximately 0.5 volt peak-to-peak which is necessary to modulate the display monitors. Positive or negative outputs of the video signal are derived from each video amplifier which may be programmed from the control panel to obtain a positive monitor display regardless of the film polarity. These outputs are also fed to the differencing circuitry to obtain the video difference function. The automatic gain control signal is obtained from the video amplifiers. The video signal is converted to an equivalent DC voltage and amplified in the AGC amplifier which control the DC voltage outputs of the phototube power supplies. Since the gains of the phototubes are proportional to the voltage applied from the power supplies an automatic gain control function results in the negative feedback loops. Base density variations of 2 have been successfully compensated in the AGC system with negligible changes in the video output. Panel controls which apply a bias to the AGC amplifiers and thus vary the video outputs small amounts, provide the vernier video gain variations necessary in the video difference mode.

All of the video functions are fed to the two monitor programmers. These programmers consist of a network of video switching relays which are controlled by a mode group of pushbutton switches on the control panel. The left programmer can provide the left video signal, the right video, the right minus the left, the left minus the right, or alternate video from the left channel and the right channel at a variable flicker rate. The right programmer can provide, the right video, the left video, shadow and/or cloud rejected video difference, and change enhanced video difference. The output of each programmer is coupled to a video driver which supplies the desired video signal to its respective monitor. A bandwidth of approximately 4 megacycles is maintained throughout the video display system.

b. Shadow and Cloud Rejection

Among the efforts which were conducted in this phase of the program was the development of a method to remove from the difference display changes caused by shadow differences which occur when the two films have been taken at different times of the day. A method of removing clouds from the difference display was also developed. Shadows cast from objects exhibit several attributes when presented on film which permits them to be isolated from the remaining information on the film. The first attribute of a shadow is that it is, typically, the most dense area of the film (assuming a positive transparency). The reverse is true for a negative transparency. In intense sunlight when shadows are most apparent this density attribute is most valid. In hazy sunlight the shadow density becomes more difficult to separate from its surroundings, however, it also becomes less objectionable on the difference display. The second attribute of a shadow is that within the shadow there is considerably less variation in the photographic density than in surrounding areas. This is due mainly to a lack of sensitivity of the film in these dark areas. This loss of spatial frequencies within the shadow is a useful characteristic which can be used for rejection. The third attribute of shadows which may

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be useful for rejection is that the orientation of all the shadows in a particular photograph will always be the same. The most useful attribute for elimination of cloud changes from the difference display appears to be that the density of the cloud, especially when reflecting bright sunlight, will be less than the remaining information on the film.

The techniques developed for rejection of shadow changes from the difference display have been based on the first attribute described, density, since it was felt that the circuit complexity required for implementation of rejection circuitry for the other two attributes would be prohibitive for the system. Since the density attribute has also been selected for cloud rejection system, common circuitry has been employed for both. The shadow and cloud rejection subsystem block diagram is shown in Figure 6. Left and right video inputs are coupled to separate inverter amplifiers. The outputs of the amplifiers are fed to a positive video "or" gate and a negative video "or" gate. The positive video "or" gate only accepts video signals from each channel which are positive with respect to the average video level. Similarly, the negative video "or" gate accepts negative video. Due to the video inversion of the first amplifiers, video in the negative channel represents clear areas in a positive film transparency, thus becoming the cloud reject channel. The positive video channel represents high density video or shadows. Video relays in each channel allow the shadow and cloud rejection circuitry to be operated either independently or simultaneously. The tunnel diode threshold detector

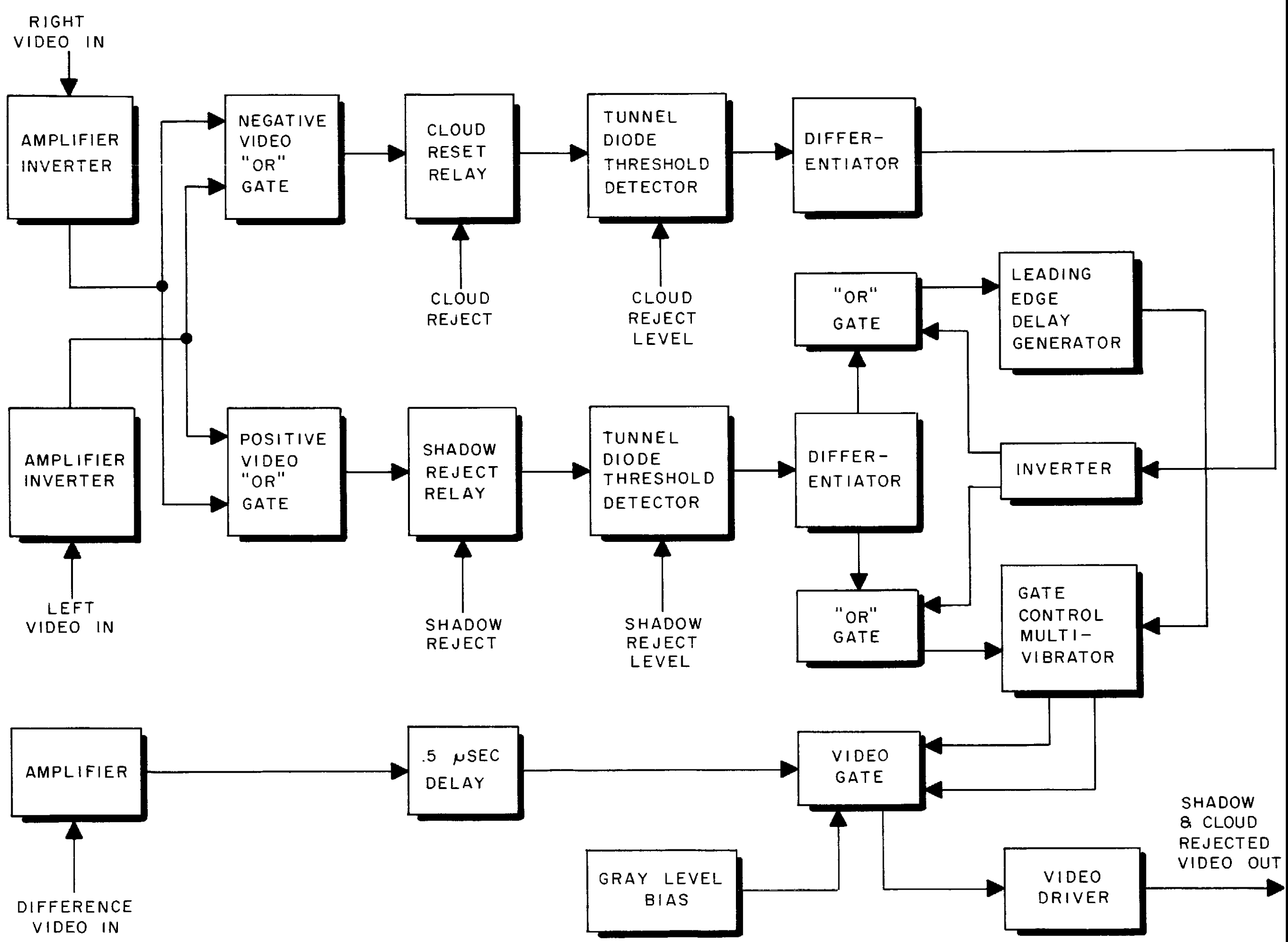

Figure 6. Shadow and Cloud Rejection - Block Diagram

circuits are pulse generators which are activated when the amplitude of the video signal reaches a predetermined level. Panel controls allow a variation in the conduction level of the threshold detectors from 0 to 100 percent of the video waveform amplitude. The output from the threshold detectors is differentiated to obtain sharp trigger pulses for operation of the remaining circuitry. The output of the cloud reject channel differentiator is inverted to provide the necessary polarity for the "or" gate which allows either shadow or cloud inputs to activate the circuitry which follows.

The finite bandwidth (and rise time) of the video signals being operated on by the rejection system makes necessary the addition of circuitry to insure that the shadow or cloud is rejected at the point in the video waveform where it begins to rise above the background and not at the point where it reaches its maximum value. If this capability is not provided, objectionable black outlining of the rejected shadow or cloud will appear. The necessary circuitry involves the use of a fixed delay of .5 microsecond in the difference video which contains the shadows and clouds to be rejected and a .3 microsecond delay in the leading edge of switching circuitry. This allows approximately .2 microsecond to perform all of the switching and gating functions before the video gate is actually opened and the shadow or cloud is rejected. The video gate consists of four diodes which are controlled by the gate control multivibrator. It operates as a series toggle switch which interrupts the difference video signal during the shadow or cloud interval.

During the interruption period the output of the gate is returned to an amplitude corresponding to the neutral gray level of the difference background by means of the gray level bias circuit. The output of the shadow and cloud rejection subsystem is then coupled into the right video output circuitry for presentation on the right monitor.

c. Change Enhancement

The video difference circuitry employed in the system utilizes an electronic subtraction process to obtain a difference display. This results in a display of the change in either black or white polarity depending on the original polarity of the change on the film and the sequence of the subtraction process. A method of displaying all of the differences between the two films as white images against a dark background has been developed which is termed change enhancement. A block diagram of the change enhancement circuitry is shown in Figure 7. Since the change enhancement circuitry generates the absolute value of the video difference, either difference video signal may be coupled into it. The nominal video level of .5 volt is amplified to a level of approximately 10 volts which is necessary for efficient circuit operation. After amplification the difference video is fed to a phase splitter which produces simultaneous normal phase and inverted phase difference video. Between the two outputs of the phase splitter all of the changes in the difference signal show up as both positive and negative video signals. Summing diodes connected to the two outputs of the

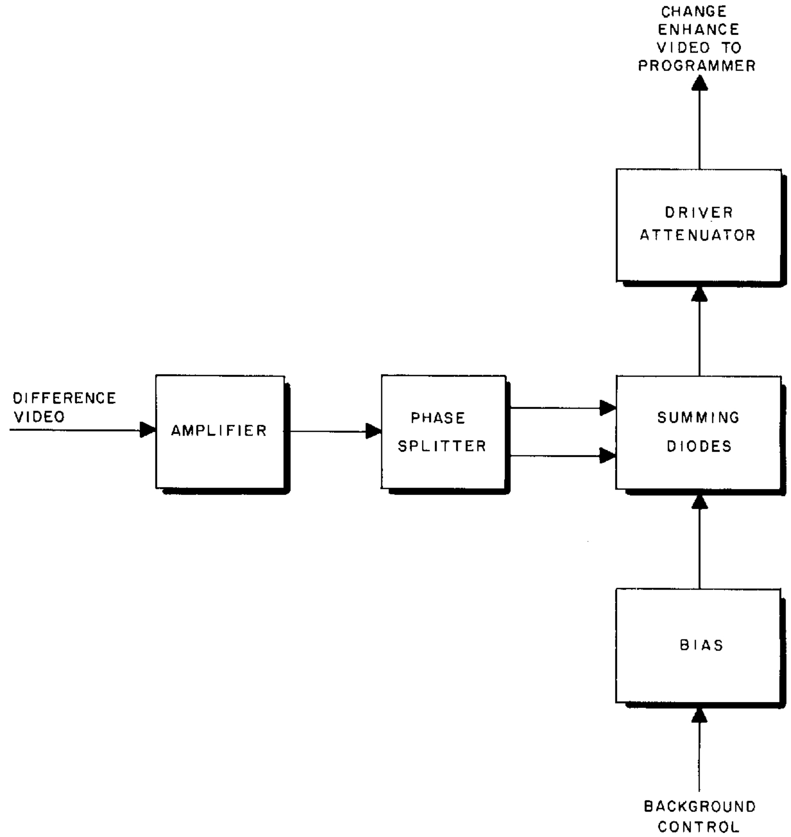

Figure 7. Change Enhancement Block Diagram

phase splitter pass only the positive amplitude video signals. Since all the changes will be displayed as positive amplitude or white differences against a dark background of the unchanged area, clipping of the background or black area may be accomplished without any loss of change information in the display. This is accomplished by applying a reverse bias to the output of the summing diodes controlled from the change enhance background potentiometer located on the control panel. The reverse bias clips out any desired amount from the background starting from a zero level and increasing to approximately one-half of the total video signal, allowing only the higher amplitude changes to be displayed. The driver attenuator stage reduces the video level down to .5 volt and provides a proper impedance match to feed the video programmer.

d. Flicker Change Detection

Flicker change detection is probably the most useful method of detecting significant changes since it allows the operator to interpret out unwanted changes such as those due to perspective differences in the imagery, small relative distortions, and some seasonal variations. In order to prevent eye fatigue, the flicker display must present each scene at a relatively constant brightness and contrast and be free of flashes or bouncing as the images are alternately switched. The flicker system which has been developed to meet these requirements is shown in the block diagram of Figure 8. The requirement that no flashing occur during the switch-over interval between images was met by deriving the switch pulses from the vertical synchronizing pulses. These vertical pulses occur during the interval when the display monitors are blanked out. The 60 cycle vertical frequency is first fed to a divide by 10 multivibrator which produces a 6 cycle rate. The variable divider is another multivibrator circuit with a control located on the front panel. The division ratio for this circuit is variable between unity and 12 which provides the flicker frequencies of one-half to 6 cycles per second. The nature of the multivibrator divider requires division of the input frequency in integral steps that result in flicker frequencies of 6, 3, 2, etc cycles per second which are time related to the vertical sync frequency. The

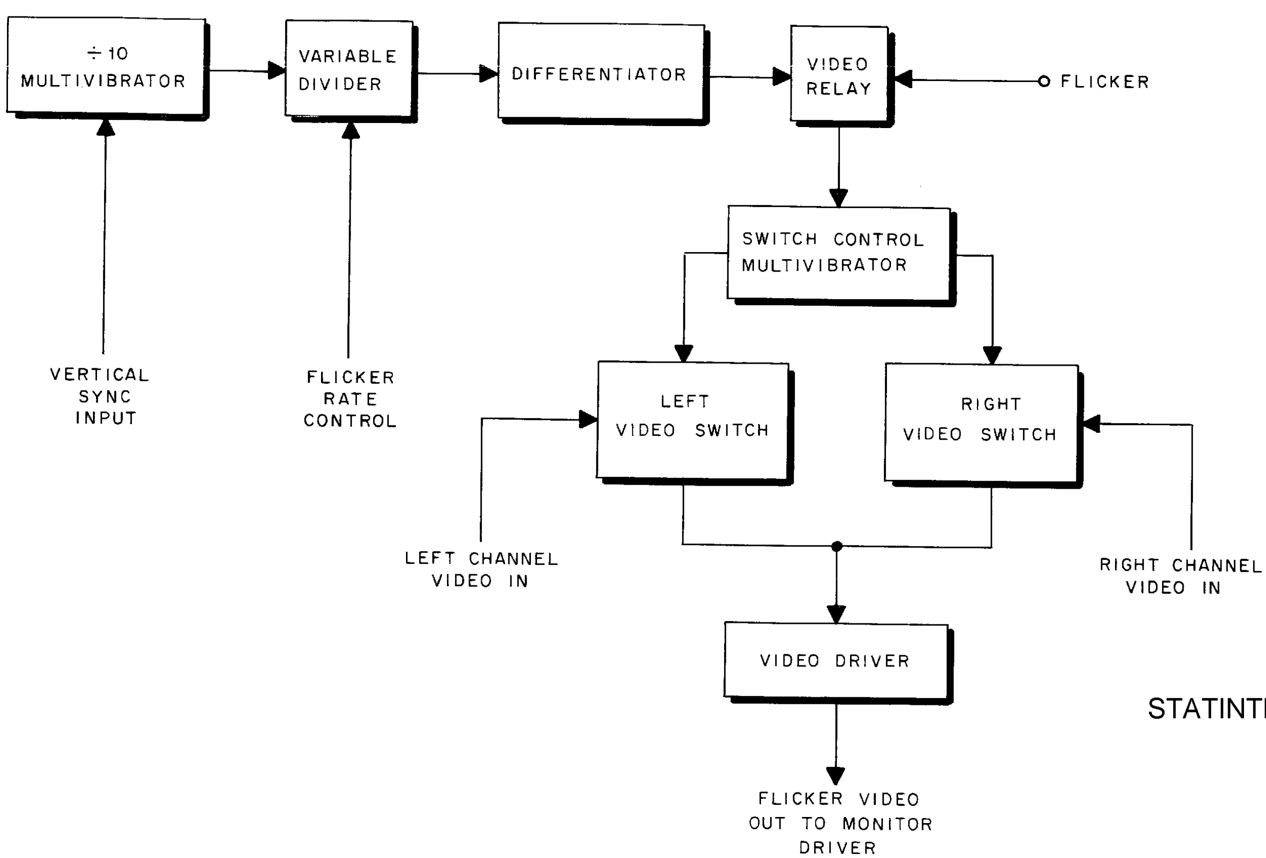

Figure 8. Flicker System, Block Diagram

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divider output is differentiated to obtain trigger pulses for the switching circuit and fed through a video relay which controls the on-off function of the flicker system. The switch control multivibrator operates at the selected flicker frequency and alternately activates the left and right video switches. The video switches are diode circuits connected as series toggle switches for their respective video inputs. The outputs of the video switches are tied in parallel and feed a driver circuit supplying the flickered video to the left monitor video circuitry.

e. Raster Line Suppression

The proximity of the change detector operator to the two display screens allows him to see the raster line construction of the displays. In order to produce a display more nearly approximating an optical image, a method for raster line suppression has been developed. The two 14-inch cathode ray tubes in the monitors were replaced by two [redacted] cathode ray tubes. These tubes are identical to the original CRT's except that each has a special set of electrostatic deflection plates which when driven produce a small vertical deflection of the electron beam. The driving circuitry for the deflection plates consists of an oscillator which produces a 25 megacycle sine wave of approximately 60 volts amplitude. The application of this sine wave to the deflection plates produces a vertical wobble of the CRT spot as it travels across the face of the tube. Horizontal synchronizing pulses from the system are fed to the spot wobble oscillator to insure that the oscillator starts at exactly the same phase for each raster line. This eliminates any beat pattern or interference between the raster frequency and the spot wobble frequency. The spot wobble amplitude is adjusted to produce a deflection amplitude of one raster line width. This condition yields the optimum raster line suppression while offering negligible resolution loss in the display.

4. SYSTEM DESIGN AND FABRICATION

a. Detailed Block Diagram

The detailed system block diagram shown in Figure 9 shows each major assembly, subassembly, circuit function, and control for the entire change detector console. The block diagram may appear somewhat complex because of the inclusion of all interconnections including controls, signals, and power supply voltages. The use of the block diagram for system assembly and layout made the complexity necessary, however. The change detector system configuration has been divided into the following areas: display generation, registration mechanism, film magazine assemblies, programmer, system power supplies, cabinet, and control panel. Each will be discussed in detail.

b. Display Generation

The display generation system consists of the components necessary to generate a variable size raster on the scanning CRT. The output video circuitry and displays are also included in the display generation area of the system, however they were discussed in Part 3 of this section.

This envelope contains

Change Detector System, Block Diagram

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Figure 9. Detailed Block Diagram

The basic system timing waveforms are generated by the synchronizer. A 31.5 kilocycle oscillator, which is phase locked to the 60 cycle power line to prevent objectionable hum bars in the output displays, is used to generate the master timing waveform. Division of this signal by 2 with a multivibrator results in the 15,750 cycle horizontal scanning frequency of the system. The 31.5 kilocycle waveform is also fed to a series of monostable multivibrators which perform the operation of $\div 3$, $\div 5$, $\div 5$, and $\div 7$ resulting in the 60 cycle field frequency which is interlaced 2 to 1 for a 30 cycle frame rate. The two output frequencies are mixed to obtain the composite synchronizing waveform that provides sync information for the display monitors and other video circuits. Equalizing and serration pulses are also generated in the synchronizer and are mixed with the composite sync waveform during the vertical blanking interval to maintain interlace in the display monitors. A composite unblanking waveform is also derived from the synchronizer. This signal is necessary to brighten the scanning CRT during the active portion of the scanning raster and to apply a cut-off voltage during the scan retrace.

The individual horizontal and vertical sync pulses are coupled to the raster generator which produces the horizontal and vertical raster waveforms. Bootstrap circuits are used to generate the linear sweep waveforms. The linearity of each output is greater than 99 percent. Raster size reduction for the area blow-up function is performed by feeding the sweep voltages into two linear precision potentiometers tied to a common shaft which are connected as variable voltage dividers. The potentiometers are driven by a small induction motor that is controlled from the magnification switches on the control panel. A CRT brightness control potentiometer is also driven by the motor. This control applies a negative bias to the CRT grid as the raster size is reduced. This is necessary in order to prevent phosphor burn on the CRT due to the high beam current density at small rasters.

The horizontal and vertical yoke drivers accept the raster inputs and supply the necessary currents to the deflection yoke on the CRT. The respective yoke windings are connected to the output of the yoke drivers in series with small sampling resistors. The current through each yoke winding-resistor combination is sampled at the resistor and fed back to the input of the yoke driver amplifier. The result is a highly linear current feedback amplifier system which is capable of reproducing any raster amplitude.

Raster positioning is accomplished by feeding a controllable bias voltage, derived from the area selection joystick on the front panel, to the horizontal and vertical position amplifiers which drive their respective position yokes. Separate raster positioning yoke windings are necessary because the raster deflection yoke windings must not contain a position bias component when the simultaneous image rotation function is performed. Rotation of the CRT raster about its centroid results in a rotation of both film images since each is being scanned by the CRT. Since no bias is present in the deflection yoke, a rotation of this yoke meets the requirements for image rotation. The deflection yoke is mounted in a large bearing assembly attached to the CRT magnetic shield. The rotating assembly is driven from a position servo whose input is derived from the simultaneous image rotation potentiometer on the control panel.

The focus regulator consists of a constant current generator which supplies a nominal 60 milliampere bias into the focus coil. A vernier control potentiometer on the control panel allows a slight variation in the bias current to optimize the CRT focus. The flat face of the scanning CRT requires a variation in the focus current as the electron beam is deflected away from the center of the screen. Dynamic focus correction within the raster is not necessary since for large rasters the raster lines are far apart and the result of spot defocusing without correction has a negligible effect on the overall resolution. For the small raster case, the raster lines are nearly overlapping, however, due to size of the raster only focus corrections for raster position are necessary. The equation for dynamic focus correction current required in the focus coil takes the form:

$$I = I_c - Kd^2$$

where

I_c is the optimum focus current at the center of the CRT

d is the radial distance from the center of the tube, and

K is a gain constant.

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Position information for the dynamic focus circuitry is derived from the output of the horizontal and vertical position amplifiers which control the raster position. Nonlinear diode circuitry operates on the position voltage inputs to provide X^2 and Y^2 functions. These functions are summed and applied to a variable gain current amplifier. Since a single focus coil is used in the system, the output current is subtracted from the static focus current to provide the complete focus function.

The high beam current employed in the CRT requires some form of protection circuitry in the event of a failure in the deflection or bias system, since a stationary spot on the CRT would result in an immediate phosphor burn. A sweep failure protection circuit and a power off delay circuit furnish this protection. The sweep failure protection circuit, as the name implies, samples the output deflection currents, and in the event of a failure, activates a relay which disconnects the unblanking signal from the CRT cathode, thereby cutting off the electron beam. This relay is also used in the automatic registration mode to cut off the CRT during automatic registration. The power off delay circuit is needed in case of a sudden interruption in the primary system power, such as, an inadvertent removal of the power plug. A relay coil is connected across the primary power input. The relay contacts are connected in series with the CRT grid bias voltage and in parallel with a large capacitor. Under normal conditions the capacitor charges to the grid bias voltage when the system is turned on. If a power failure occurs the relay contacts are opened and the capacitor will hold the charge on

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the grid until the remaining high voltage and other voltages decay to a safe value.

c. Registration System

The registration mechanism is shown schematically in Figure 10. It performs the following functions: right image X and Y alignment, left image X and Y alignment, azimuth alignment, scale factor alignment, right image tip alignment, and left image tilt alignment. Sixteen servo systems are required to perform the manual and automatic registration functions listed above. The servo systems are Type I position servos employing velocity feedback to improve linearity and minimize positional overshoot. Figure 11 shows a typical servo system used for registration. The input to the servo is a DC voltage from a control potentiometer located on the control panel or some other mechanism. The input voltage is summed with a voltage of opposite sense from the follow potentiometer which is driven from the gear train or mechanism to be displaced. If these two voltages are not equal and opposite an error voltage is produced at the output of the summing network. This error voltage is converted to an AC signal in the diode modulator which operates 90 degrees out of phase with the 115 volt line frequency in order to drive the 2 phase servo motor. A preamplifier and gain control allow the overall servo system gain to be set at the proper level. The servo amplifier is a packaged unit purchased from the [redacted] The transistorized amplifier is capable of driving servo motors requiring up to 9 watts of input power. The servo

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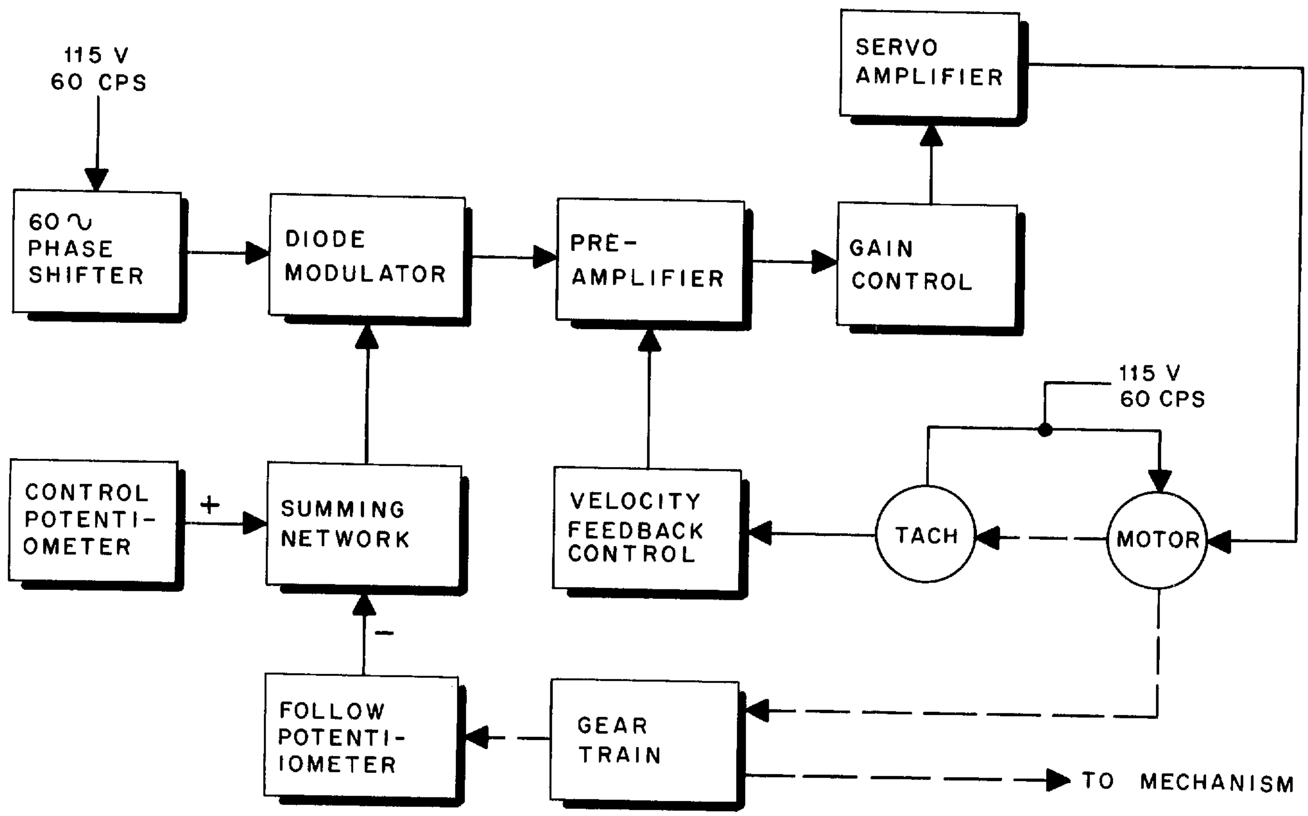

Figure 11. Typical Position Servo

electronics assembly is shown in Figure 12. Three sizes of servo motor-tachometers are used in the registration system. They include the 3.5 watt, size 11, motors which drive the smaller mechanisms; the 6 watt, size 15, motors which drive the intermediate mechanisms, such as the rod servos, and dove mirror servo; and the 9 watt, size 18, motors which drive the film magazine assemblies and other large systems. These 60-cycle motor-tachometers are manufactured by [redacted] and are designed to be driven by the transistorized servo amplifier. The tachometer is used for

rate feedback to the position servo and produces a 60-cycle output whose amplitude is proportional to the velocity of the motor. The gear-train produces the necessary mechanical gain to position the mechanism. Anti-backlash gearing is used almost exclusively in the gear-train to insure the tightest possible servo loop. Wherever possible carbon film or plastic omposition potentiometers have been used for the control and follow pot functions since they exhibit infinite resolution and low noise properties necessary for an accurate servo loop.

Considerable effort has been expended in the development and fabrication of the electronic and mechanical components for the various servo systems since smooth response and positional accuracy of the servos ultimately affect the operator's ability to detect changes between the imagery.

Manual X and Y registration of each image is attained by applying lateral and longitudinal motions to the top of each guide rod which move the individual objective lenses. The motions are applied to each guide rod from a guide rod drive assembly shown in Figure 13. Motion in each axis is obtained from two orthogonally mounted sets of precision ball slides. Ball screw mechanisms transform the rotational input from the motor and gear-train to the translation required. Each assembly is incorporated into a position servo loop with follow potentiometers coupled to the gear-train and control potentiometers located on the control panel. Another potentiometer is mechanically coupled to each follow

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potentiometer to furnish X and Y position information from each guide rod to the field lens and correlation mask servos. The rod positioning servos can only be activated during the manual registration mode.

Rotation of one scene relative to the other for azimuth corrections is achieved with the dove mirror assembly attached to the right guide rod. The assembly contains three front surface mirrors; one mounted parallel to the optical path and the other two at an angle of 27 degrees. The mirrors are mounted in a housing which rotates on ball bearing assemblies located at each end. Shims inserted under the angular mirrors insure that the optical center of rotation corresponds to the mechanical center of rotation. The use of three mirrors results in a reversion of the CRT raster image in the right channel. However, a similar reversion exists in the left channel due to the folding mirror in the optical path and thus the two images are similar. The dove mirror system possesses the unique property that the optical rotation angle is twice the mechanical rotation angle. Thus, for 360 degrees of image rotation the dove mirror assembly was designed for 180 degrees of mechanical rotation. A driving gear mounted to the top bearing surface couples the assembly to the gear train and servo motor. The position servo loop is controlled from the rotation potentiometer on the control panel. A secondary support rod attached to the primary guide rod allows a three-point bearing suspension to be used for axial motion of the dove mirror assembly when the scale factor adjustment system

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is operated.

Scale factor differences between the two scenes are corrected by applying an axial motion to the objective lens in a direction along the guide rods. The right and left lens holding assemblies are connected to the scale factor drive mechanism by a ball slide assembly similar to that used in the guide rod drive assembly, to prevent interference between the translational and axial movements of the lenses. The scale factor drive mechanism consists of an arm which pivots about its center, coupled to the lens holders at each end, and driven at one end by a ball bearing screw, gear train servo motor combination. The magnification range for each channel is variable from .7X to 1.4X. Due to the equal and opposite axial motion of the lenses a total magnification range of 2X is attainable. The equal and opposite motion of the scale factor registration assembly results in a balanced load on the servo system, thus eliminating any need for a bias or non-linear input into the servo amplifier.

Obviously, axial motion of lenses alone is not sufficient to maintain focus as the magnification is varied. The lenses and film planes are positioned by a unique autofocus linkage developed by
A schematic of this linkage for one channel is shown in Figure 14. A right triangular linkage is retained by two slides AB and CD which are spaced a distance, f, apart, where f is the focal length of the lens. Points E, F and G are retained vertically by the two slides. The object and image positions are located a distance equivalent to

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focal length away from E and G as shown, while the lens is positioned at F. In the system where the object plane (CRT) remains stationary, E is fixed and F and G allowed to move horizontally along the slide.

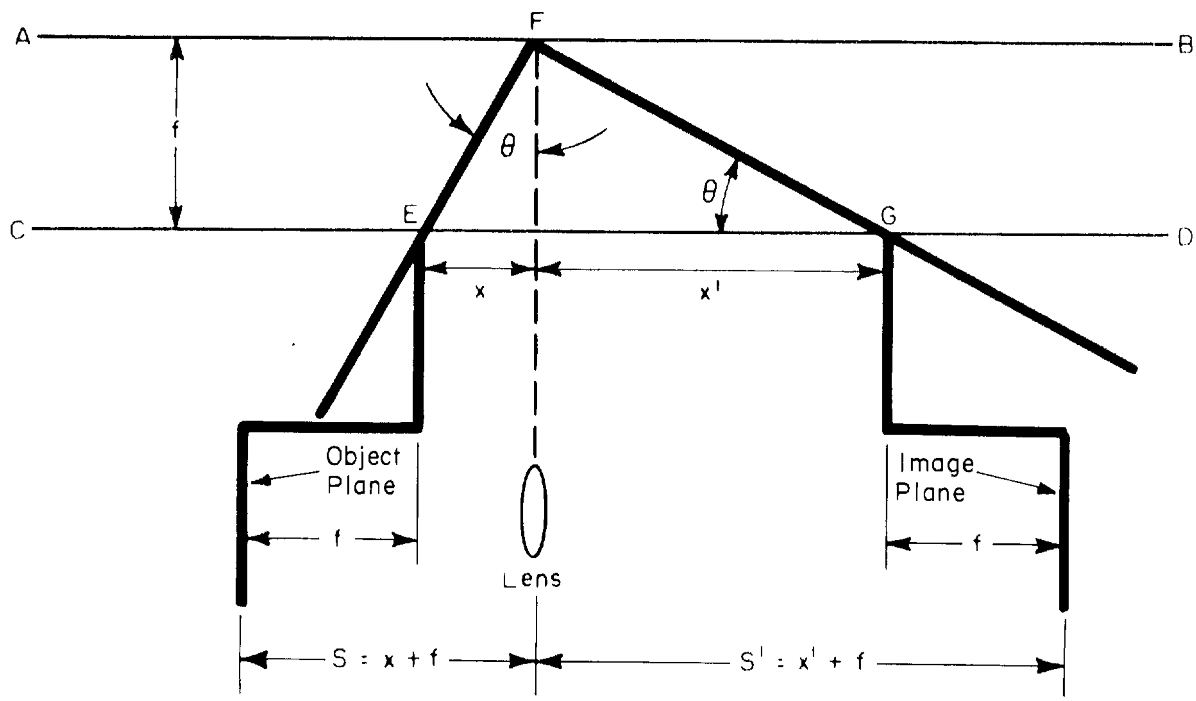

Figure 14. Autofocus Linkage

From the linkage geometry, we have

$$X' = f \cot \theta$$

$$X = f \tan \theta$$

so that the image and object distances S and S' from the lens become

$$S = f(1 + \tan \theta)$$

$$S' = f(1 + \cot \theta)$$

Substituting these values into the lens equation:

$$\frac{1}{f} = \frac{1}{f(1 + \tan \theta)} + \frac{1}{f(1 + \cot \theta)}$$

$$= \frac{1}{f}\left[\frac{1 + \cot \theta + 1 + \tan \theta}{(1 + \tan \theta)\ (1 + \cot \theta)}\right]$$

$$= \frac{1}{f}\left[\frac{2 + \tan \theta + \cot \theta}{2 + \tan \theta + \cot \theta}\right]$$

$$= \frac{1}{f}$$

Thus the identity is proved and the autofocus linkage is shown to satisfy the lens equation insuring focus when S and S' are varied.

Due to loading considerations, the linkage in the system design does not physically drive the film magazine assembly. Instead it drives a potentiometer whose output is used to drive a servo which, in turn, positions the film magazine assembly. The two film magazines are each mounted on three precision ball slide mechanisms. The right channel magazine moves vertically, while the left channel magazine moves at an angle of 12 degrees from vertical, which is the nominal angle of the left guide rod when centered. Since the weight of each magazine assembly is over 50 lbs, negator springs have been attached to the magazines to provide a counterbalance function. Positioning of each magazine is controlled from a servo motor, gear train, and precision ball screw combination. A bias voltage from a fine focus potentiometer on the control panel is summed with the output voltage from the control potentiometer driven by the autofocus system to compensate for any inaccuracies in the autofocus linkage.

The tip and tilt registration functions are performed by the right and left film magazine assemblies, respectively. Tilt motion has been achieved by mounting the right magazine assembly in two ball bearing supports at each end of the magazine. The center of rotation is about the longitudinal centerline of the film aperture. Tip motion on the left magazine has been accomplished by a similar, but larger, bearing assembly whose center of rotation is about the vertical centerline of the film aperture. Both tip and tilt servos are controlled from the front panel.

Components of the registration system which accomplish automatic registration of the two film images include: the X,Y lens drive, nutator, movable mirror, correlation mask and half-mask, field lens and mirror, lens stop, and density wedge servo. The electronic circuitry associated with the automatic registration mechanisms include the search generator; match point detector; X and Y coordinate storage; phase discriminators; error amplifier, search, lock-on, and dynamic iteration control; field lens summing networks; and correlation mask summing networks.

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When the automatic registration switch is activated, the programmer supplies the necessary control voltages to set-up the optical system for the automatic registration mode. In the right film magazine the backlight is energized and the mirror which normally reflects light from the CRT onto the phototube is removed (Figure 3). A front surface mirror is inserted in the optical path near the CRT at an angle of 45 degrees with vertical. A real image of the right film appears at the mirror surface behind the field lens. This mirror is set at an angle of 90 degrees from the CRT surface and performs the function of reflecting the image of the right film into the left channel optical system. The point at which the mirror is introduced in the optical path is identical to that of the CRT phosphor surface. The off-axis nature of the optical system makes it necessary to control the lateral and longitudinal position of the field lens-mirror combination as a function of the X and Y positions of the guide rods. X and Y position servos with inputs derived from the auxiliary follow potentiometers on the guide rod drive servos furnish this capability. The respective X and Y position inputs from the guide rod servos are fed to special summing networks containing diode logic which insures that the guide rod with the maximum deviation from the nominal optical centerline controls the position of the field lens-mirror combination.

The correlation mask and half-mask mechanism is located in front of the field lens-mirror combination. The correlation mask is constructed of four Teflon rectangular sheets. One pair of the sheets perform a lateral closure of the mask and the other pair perform a longitudinal closure. Rack and pinion gear drives position each half of the mask in equal and opposite direction resulting in closure about the center of the mask aperture. Since the size of the mask opening required is proportional to the overlap area of the two films, the X and Y mask size servo information is derived from the rod servos and summed in the same manner as for the field lens servos. Scale factor differences between the films are sensed by an auxiliary follow potentiometer on the scale factor servo and fed to both X and Y sections of the mask. The area of the mask opening is a maximum when both optical channels are set at unity magnification and decreases linearly when the scale factor is varied. In addition, a factor of .7 is introduced into the mask area which allows for the worst case azimuth error of 45 degrees between the two films. The half-mask consists of a Teflon slide driven by a solenoid. When activated during the azimuth and scale factor registration modes, the half-mask covers half of the mask aperture.

The lens drive mechanism shown in Figure 15 is used for automatic registration of lateral and longitudinal position errors between the two films. Two servo motors coupled to gear trains drive two scotch yoke mechanisms to achieve lens translation in both axes. The lens displacement for a linear input to the servo is sinusoidal for this type of mechanism. Sine/cosine follow potentiometers coupled to the gear train duplicate the lens displacement function to provide a feedback voltage proportional to the lens position.

During the search operation the lateral lens drive servo is allowed to slew at the maximum rate of 1 cycle per second. The longitudinal lens drive servo is connected as a position servo and a ramp voltage of 20 seconds duration is introduced to the servo

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input. The ramp voltage is derived from the Y search generator which contains a linear bootstrap circuit. The resultant raster search pattern of the lens is contained in a square .1875 inches on a side. Assuming a nominal optical magnification of unity in each channel, the search pattern of the right film imaged on the left film is contained in a square .375 inches on a side. The distance between lateral cycles of the raster search pattern at the left film plane,

$$d = \frac{.375 \text{ inches}}{20 \text{ sec} \times 1 \text{ cycle/sec}}$$

$$= .01875 \text{ inches/cycle} \quad .$$

The maximum search miss distance (the distance between the exact point of registration of the two images and the search displacement), assuming idealized match point detection circuitry, will be no greater than one-half of this distance. This figure places a lower limit on the nutation radius that can be employed and still achieve a reliable dynamic lock-on when using films containing mostly fine details.

The match point detection circuitry is programmed to accept the match point signals from the left phototube during the search mode. Two stages of differentiation operate on the match point waveform to eliminate any effects of shading in the two scenes. The upper bandwidth limit in the double differentiation is restricted to 60 cycles in order to reduce noise present in the correlation signal. The output of the differentiation is amplified and fed through a series diode to charge a capacitor. When the search cycle approaches and passes through the point of exact registration, a series of match signals are generated. The capacitor charges to the amplitude of each of the match signals until the maximum amplitude match signal is reached. Match signals of smaller amplitude beyond this true match point are prevented from charging the capacitor by the diode. A pulse generator coupled to the amplified output of the capacitor is activated by each match signal. The last output of the pulse generator therefore, represents the true match point.

The X and Y coordinate storage circuits derive one input from the respective follow potentiometers on the lens drive during search. The other input is coupled to both coordinate storage circuits from the pulse generator in the match point detector. A diode gating circuit used as a series switch is closed by the pulse, allowing the position voltage from the follow potentiometer to charge a capacitor. Each time a pulse occurs a voltage is stored on the capacitor which corresponds to the lens position at that instant in the search cycle. Since the last pulse received by the two coordinate storage circuits represents the true match point, the voltages stored on the capacitors at the end of the search cycle represent the coordinates of the true match point. The stored coordinate voltages are fed back to the lens servo inputs which position the lens to the match point.

The circuity that connects the coordinate storage outputs to the lens servos is called the correlator signal programmer. It consists of a network of switching relays which route the various correlation signals to the proper registration servos during each of the phases of the automatic registration sequence. Control voltages for this operation are derived from the automatic register programmer.

Following the search and lock-on to the match point, the nutator is energized. The nutation mechanism shown in Figure 16 consists of two concentric-mounted optical wedges driven by a gear-train and synchronous motor. While the highest possible nutation frequency is desirable from the standpoint of servo loop response, design compromises limit the frequency to 80 cycles per second. The power source frequency of 60 cycles per second sets the maximum motor synchronous speed at 3600 RPM. Inertia considerations limit the gear-train set-up ratio to 1.3 resulting in the 80 cycle nutation rate. An alternator coupled to the gear-train furnishes two 80 cycle reference voltages phased 90 degrees apart which are required by the phase discriminators. The retaining rings which hold the wedges are constructed to allow a relative displacement between the wedges to change from zero to 180 degrees as the nutator is activated. When the wedges are properly positioned in the retaining rings, a maximum nutation diameter will result when the nutator is running. As the nutator slows to a stop during the viewing mode, the inertia of the top wedge allows it to displace 180 degrees from the running position. Since the wedges are identical, the optical displacements cancel each other in the reset condition.

A wedge deviation angle of 3 minutes has been selected as the best compromise between registration accuracy of the dynamic matching process and dynamic lock-on range. The total deviation for the two wedges is 6 minutes. For the unity magnification case the resultant nutation radius is .003 inches. This is well above the minimum limit defined by the search miss distance even when errors caused by inaccuracies in the coordinate storage circuitry are included.

An 80 cycle sinusoidal error voltage is generated at the output of the left phototube when small translational errors are encountered during the nutation process. Amplification of the error voltage is performed by the error amplifier which feeds the lateral and longitudinal phase discriminators. The phase discriminators are sampling full-wave rectification circuits that convert the error signal into the respective lateral and longitudinal DC error components. The sampling inputs for the phase discriminators are obtained from the two reference voltage outputs of the alternator which are in quadrature. When the alternator is properly phased with the nutation wedges, the DC voltages out of the phase discriminators faithfully represent the lateral and longitudinal position error voltages. The position error voltages are fed through the correlator signal programmer to the lens servo inputs. The lens is driven to the point which produces a minimum error signal.

Automatic correlation in azimuth and scale factor is initiated after insertion of the half-mask and disconnection of power to the lens servo. The nutation process is continued resulting in the generation of error voltages at the output of the phase discriminators. Since only half of the original area is being correlated in this mode, the longitudinal phase discriminator produces an error voltage proportional to an azimuth error. The lateral phase discriminator produces an error voltage proportional to a scale factor error. The fact that the longitudinal phase discriminator output is dependent only on an azimuth error can be determined by considering that the entire correlation area is composed of four equal quadrants. When the half-mask is inserted only the upper and lower right quadrants remain for correlation at the left film plane. Since the center of rotation of the azimuth servo is about the center point of the entire correlation area, the lateral error signals generated by correlation of targets in the upper and lower right quadrants are equal and

opposite and, therefore, cancel. Similarly, the center of enlargement of the scale factor system is at the center of the correlation area, resulting in a cancellation of the longitudinal error components. The two error signals are fed through the correlation signal programmer to the azimuth and scale factor servos to produce a simultaneous null in both.

This type of correlation system reaches the exact registration point of the two images through successive stages of convergence of the four degrees of registration. Three complete iteration cycles in X-Y and azimuth-scale factor are required.

The range of contrast and base density of the imagery to be analyzed in the system dictates the need for a method of setting the correlation gain. The density wedge servo furnishes this function by controlling the amount of backlight energy that reaches the correlation system. The density wedge mechanism consists of two contra-rotating circular density wedges located adjacent to the backlight in the right film magazine. The wedges are driven by a position servo. The two wedges are positioned such that the density variations are opposite to maintain constant illumination of the right film image. The density range of each wedge varies from near 0 to 2, resulting in a total range for both wedges of 4. The servo is positioned by comparing the DC output voltage of the left phototube with a fixed reference voltage. The servo drives until the voltage from the phototube is equal in magnitude to the reference voltage. Within the range of the wedges, a constant light input to the phototube is maintained, regardless of the base density and contrast of the films. The value of the reference voltage has been determined experimentally, by inserting films with various base densities and observing the match point detector output. An exact setting is not required since the correlation circuitry can accept a fairly wide range of inputs.

d. Film Drive Assemblies

The film drive assemblies contain the two film transport mechanisms, the frame counting sensors, and the cross-hair positioning mechanisms. Each film transport mechanism is a tension balancing system and is shown schematically in Figure 17A. The power required to translate the film and supply tension to eliminate slack in the

A

B

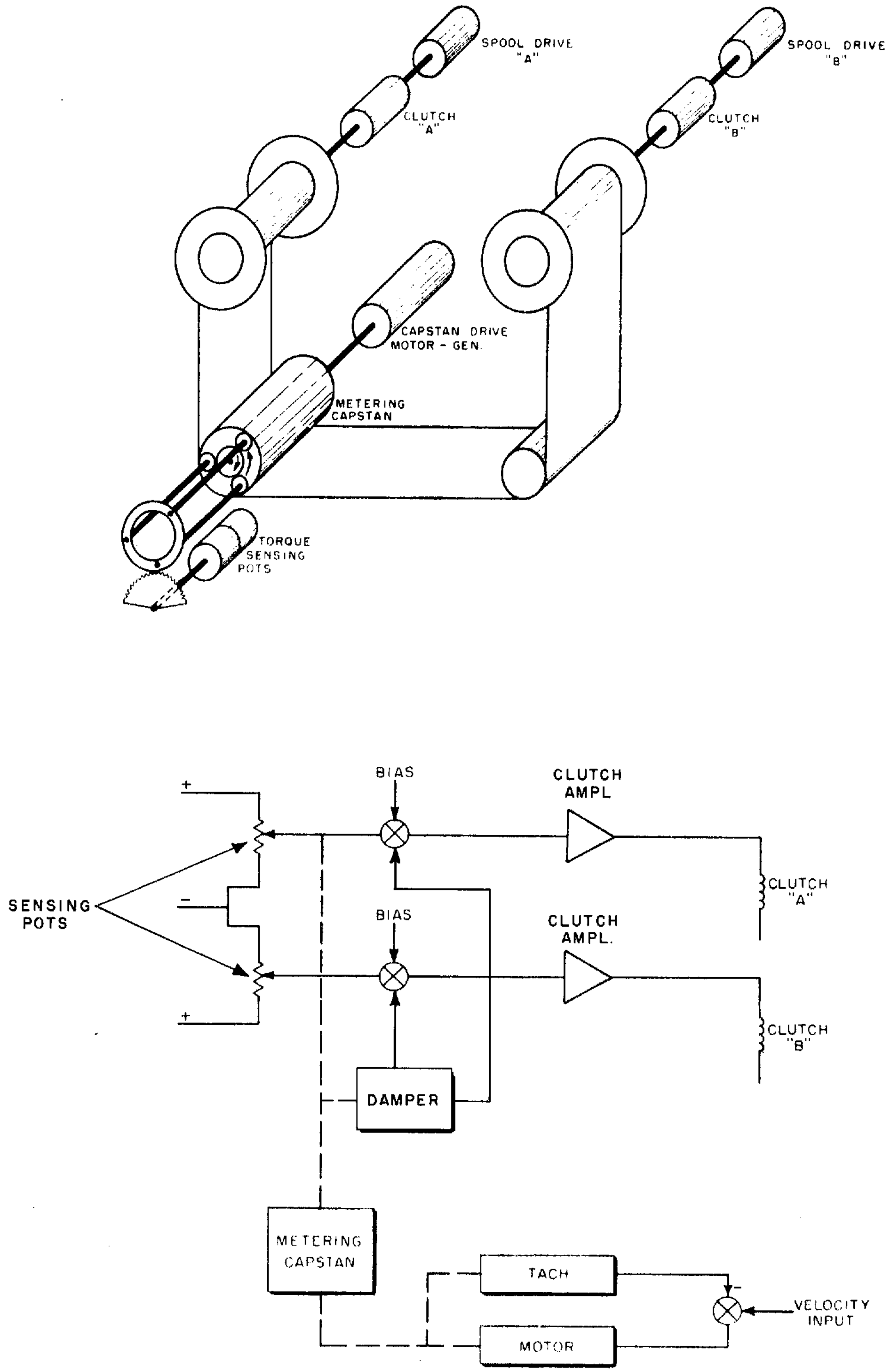

Figure 17. Film Drive System

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film is supplied by drive motors on the film spools. Between the motor shafts and the spool driving shafts is located a magnetic particle or hysteresis clutch. The clutches have the characteristic of transferring torque proportional to voltage. The amount of torque transmitted to each spool is controlled by a tension balancing capstan. The capstan is constructed (see Figure 18) in the form of a differential in which one input is the difference in film tension and the other is film position relative to the aperture. The output of the differential capstan (see Figure 17B) is a pair of control potentiometers that control the torque output of the film spool drive clutches through a pair of differential amplifiers. The amplifiers have two inputs - one the tension unbalance, and the other the tension "bias" to maintain sufficient film tension to insure against a slack film loop. The difference in film tension results in a deflection of the potentiometer's arms which, when the electronic feedback loop is closed through the clutch amplifiers, corrects any tension unbalance about the capstan. Velocity feedback to minimize film overshoot while maintaining a tight control loop is achieved through the use of the velocity damper shown in Figure 18. The velocity damper consists of a solenoid with a permanent magnet slug. The permanent magnet is attached to the sensing potentiometer lever arm. As the lever arm moves, an output proportional to the arm velocity is obtained from the damper. This output is fed back to the clutch amplifiers to provide the inverse velocity feedback function.

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Film motion is achieved by driving the shaft of the differential capstan from a velocity servo. A two speed gearhead provides the necessary speed control to operate the film drives in two velocity modes.

Each film frame counter and frame position indicator derives position input signals from an optisyn which is coupled to a roller driven by the film motion. The optisyn is a very low inertia, low friction transducer capable of producing precisely spaced sinusoidal outputs as the input shaft is rotated. The output of the optisyn consists of two sine waves in quadrature. The relative phase of the two output waveforms depends on the direction of rotation of the input. Pulse generating circuitry coupled to the outputs of the optisyn consists of a phase sensitive zero crossing detector. There are two outputs from each pulse generator and, for a given direction

[redacted]

of film motion, pulses occur at one of the outputs. The frequency of the pulses is dependent on the number of zero crossings of the sinusoidal outputs from the optisyn. When the direction of rotation is reversed, the phase relationship between the two sine waves reverses, and the pulses appear at the alternate output.

The selected optisyn produces 400 pulses per revolution when coupled to the pulse generation circuitry. The film motion sensing roller which drives the optisyn, was machined to a diameter of 1.27 inches. As a result, one output pulse is generated for each .01 inch or .25 millimeter of film travel. Flip-flop binary counters are used to count the number of input pulses for a specific frame length. A maximum of 12 flip-flops are required to accommodate frame lengths between 50 and 1000 millimeters. When the count reaches the predetermined number for a given frame length, a pulse is generated from the binary chain to advance the solenoid type frame counter. In the forward direction triggers are taken from the conventional "zero" side of the flip-flops. However, in the reverse direction these triggers are gated off by a direction gate generator, all triggers are taken from the complimentary side of the flip-flops, and a reversing coil is switched into the readout counter. The counting circuitry has been designed to accommodate four frame length settings.

[redacted]

The frame position indicator contains counting circuitry which is similar to the frame counter, although simplified. A division of the input pulses by 4 results in an output for each millimeter of film travel. Reversing circuitry is identical to that used in the frame counter. The indicators for the frame counting and frame position functions are identical. The frame counter indicator is programmed to read frame number and the frame position indicator reads in millimeters. Each may be preset to any desired number prior to activation of the film drives.

The lateral and longitudinal cross-hair positioning mechanisms are mounted on the film drive assemblies in close proximity to the film apertures to insure that the cross hairs are within the depth of focus of the objective lenses. Individual position servos are employed for each axis of cross-hair motion. Control is provided by potentiometers attached to the respective joysticks on the control panel. Ganged follow potentiometers on each mechanism supply both the feedback voltage for the position servo and a position voltage to control the cross-hair position indicators. The cross-hair position indicators are voltmeters calibrated to read in centimeters. Full scale accuracy of the meters is within 2 percent.

e. Power Supplies

The prime power sources employed in the system are listed in Table IA. All are commercially available units with the exception of the high voltage power supply. It was specifically developed for the change detector application. Each is designed to operate from a 60 cycle, single phase input source over a range of 105 to 125 volts. In addition, several power supplies have been developed to meet specialized requirements in the system. These supplies which derive

TABLE IA- SYSTEM POWER SOURCES

Power Source	Output Voltage	Regulation	Application
Sola Regulator	118 V AC - 60 cycles	1 Percent	Servos and other components requiring regulated line voltage
28 Volt Supply	24 - 32 V DC	Unregulated	Relays, lamps, DC motors
$\pm$ 30 V Lambda Supplies	+ 30 V and - 30 V DC	.05 Percent	Prime power for all semiconductor circuitry in system
Bias Supply	- 125 V DC	.2 Percent	CRT grid bias
High Voltage Supply	17.5 KV DC	.005 Percent	CRT anode supply

their input power from the prime power sources, include the $\pm$ 20 volt reference supplies, the 2 KV bias supply, and the backlight regulator. The $\pm$ 20 volt reference supplies furnish reference voltages to the servo control and follow potentiometers. The need for special voltage supplies for the potentiometers exists because the heavy loading on the $\pm$ 30 volt supplies causes undesirable voltage drops and noise at remote points in the system which would adversely affect the operation of the servo systems. The $\pm$ 20 volt supplies provide the necessary pure DC output. A two kilovolt bias required by the CRT acceleration grid is obtained from a voltage divider connected to the 17.5 KV high voltage supply.

A DC source is required for the backlight during the automatic registration mode in order to minimize any noise in the correlation signals emanating from the backlight. The output of the AC regulator is rectified and filtered in the backlight regulator resulting in a 108 volt DC output. Since the nominal lamp voltage is 115 volts, an extended lamp life results from the lower input voltage.

f. Programmer

The system programmer provides three basic functions. The first is to apply power to the various components and systems upon initiation of the main power switch in a sequence which will insure that no components are damaged. The power sequence is controlled from a motor driven timer, which provides an output at T = 0; T = 15 sec; and T = 60 sec. At T = 0 all components, such as tubes which require a warm-up period and components which are unaffected by a sudden application of power, are activated. At T = 15 sec power is applied to the $\pm$ 30 volt power supplies, resulting in an application of power to all parts of the system except the CRT high voltage supply. The high voltage supply requires a one minute warm-up period prior to application of a load. At T = 60 sec power is connected to the high voltage supply output circuitry and the system is ready for operation. The timer is constructed such that in the event of an interruption of primary power to the system, it will reset to zero. Upon restoration of power the sequence will be repeated.

The second function of the programmer is to provide control voltages to the various components during the viewing and manual

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registration modes. Power relays automatically provide control voltages to the movable mirror, backlight insertion motor, lens stop solenoid, and other components connected with the viewing mode following the power program sequence. Initiation of the manual register switch activates control relays which energize the manual registration servos.

The third programmer function is to furnish the automatic registration sequence control voltages. The control relays which energize the various correlation components, are activated by a rotary stepping switch. Actuating pulses to step the switch are derived from a bootstrap timing circuit and pulse generator. The time duration of each step is controllable from individual potentiometers connected to the bootstrap circuit. The automatic registration sequence provided by the programmer is shown in Table II.

TABLE II - AUTOMATIC REGISTRATION SEQUENCE

Code	Time Duration	Function	Components Affected
AR1	10 sec	Initiation of automatic registration	Movable mirror, lens stop and backlight activated and held on throughout cycle. Density wedge set to max. density
AR2	5 sec	Correlation gain	Nutator operating, density wedge servo operating
AR3	5 sec	Nutation stop	Nutator and density wedge servo deactivated
AR4	30 sec	Search and Lock-on	Lens servo operating
AR5	5 sec	Dynamic X and Y registration	Nutator - on; lens servo operating
AR6	5 sec	Scale and azimuth registration	Nutator - on; scale factor and azimuth servos operating

TABLE II - (Cont'd.)

Code	Time Duration	Function	Components Affected
AR7	5 sec	Dynamic X and Y registration	Same as AR5
AR8	5 sec	Scale and azimuth registration	Same as AR6
AR9	5 sec	Dynamic X and Y registration	Same as AR5
AR10	5 sec	Scale and azimuth registration	Same as AR6
RESET	-	Automatic registration - off	All automatic registration components off or reset to view mode

In the event of an interruption of power during the automatic registration cycle, the stepping switch will automatically reset itself when power is reapplied.

g. Control Panel

With the exception of the film loading switches, all controls necessary to operate the change detector are located on the control panel which is shown in Figure 19. Controls associated with the right film and right display monitor are generally located on the right side of the control panel and those associated with the left film and monitor are located on the left side of the panel.

The POWER-ON switch located in the upper right corner of the control panel controls the complete system power. Approximately 1 minute is required after this switch is activated before full power

is applied to the system.

The film polarity switches, LEFT FILM POS-NEG and RIGHT FILM POS-NEG provide the proper display polarity on the respective display monitors. To obtain the best grey scale reproduction of the input films these switches should be set to the position corresponding to the polarity of the input films, i.e. POS for film positives and NEG for film negatives.

Film motion is accomplished by activating the controls associated with the RIGHT FILM ADVANCE controls and LEFT FILM ADVANCE controls. Both control groups contain a SLOW-FAST switch which enables two basic film speeds to be employed, a slow speed for film positioning and a fast speed for film slewing. A vernier control on each of the speed ranges plus film direction control is provided by the REV - FWD lever arm. Film speed is proportional to the displacement of the REV - FWD lever arm which is spring loaded to return to the center or stop position when pressure is released.

Manual registration of the two images can be accomplished by pushing the MANUAL register switch. This activates the RIGHT FILM MANUAL ALIGNMENT and LEFT FILM MANUAL ALIGNMENT control groups. The RIGHT FILM MANUAL ALIGNMENT control group contains a "Y" CONTROL which permits vertical adjustment of the right film image, an "X" CONTROL which permits lateral adjustment of the right film image; and a ROTATION CONTROL which rotates the right film image for manual adjustment of azimuth errors between the two film images. The LEFT FILM MANUAL ALIGNMENT control group contains a "Y" CONTROL and "X" CONTROL which permit vertical and horizontal adjustment of the left film image, and the SCALE CONTROL which provides a scale factor correction capability between the two images. Additional manual registration capability is provided by the LEFT FILM - TIP and RIGHT FILM - TILT controls located on the left side of the control panel.

Automatic registration of the two images is achieved by activating the AUTO registration switch located in the lower right center of the control panel. Activation of the AUTO register switch deactivates the manual registration controls except for the two tip and tilt controls. Completion of the automatic registration sequence is indicated when the AUTO register switch button disengages and the indicator light goes out. The two SCALE CORRECTION lights CCW and CW give an indication that the scale factor adjustment servos have been moved from the position set manually by the automatic registration process. If further manual scale factor correction is determined to be necessary after automatic registration has taken place, the SCALE FACTOR control should be rotated in the direction indicated until the light goes out. This must be done prior to reactivation of the MANUAL registration switch to prevent the scale factor servos from returning to the position that was originally set in manually; thus losing the benefit gained by the automatic registration. The ROTATION CORRECTION lights, CCW and CW operate in the same manner as the SCALE CORRECTION lights. If, after automatic registration, further manual adjustment of the rotational displacement between the two images is desired, the ROTATION CONTROL should be moved in the direction indicated by the light.

The displays available on the left monitor are controlled by the group of five switches located on the left center of the panel. These include: LEFT FILM, RIGHT FILM, FLICKER (alternate display of left and right film images), VIDEO DIFF, L-R (left film minus right film), and VIDEO DIFF, R-L (right film minus left film). The FLICKER RATE control located above the FLICKER switch allows adjustment of the rate at which the two images are presented on the left monitor in the flicker mode. The two CONTRAST controls for the LEFT FILM and RIGHT FILM are located above the two video difference switches. The system normally employs automatic contrast control circuitry to provide a constant contrast display for both the left film image and the right film image regardless of the film contrasts. The LEFT FILM and RIGHT FILM CONTRAST controls are normally used as vernier controls to adjust for slight differences in contrast left by the automatic contrast control system. For those cases where the range of the CONTRAST controls is not sufficient, two toggle switches labeled AUTO-MANUAL have been provided on the front of the control panel. When the switches are in the AUTO position the automatic contrast circuitry is operative. The MANUAL position permits full contrast variation on the CONTRAST controls.

The display presented on the right monitor is controlled by the following switches: LEFT FILM, RIGHT FILM, SHADOW REJECT, CLOUD REJECT, and CHANGE ENHANCE. The latter three switches may be operated individually or in any combination to provide the maximum capability for rejection of undesired changes. Activation of either the LEFT

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FILM or RIGHT FILM switch is required to disengage any of the other three switches.

The level at which the shadow and cloud changes are detected and rejected is determined by the SHADOW REJECT LEVEL and CLOUD REJECT LEVEL controls. The CHANGE ENHANCE BACKGROUND control allows the background level to be varied from a point where all of the changes are presented to a point where only the highest contrast changes are presented.

Any area of both of the film images within the film apertures may be selected and magnified through the use of the AREA SELECTION joystick and the MAGNIFICATION INCREASE-DECREASE switches. A movement of the joystick toward the display monitors results in a display of the upper portion of the film images. Similarly, a right hand movement of the joystick results in a display of the right side of the film images. Simultaneous rotation of both film images to provide viewing from any orientation is available by rotating the ORIENTATION OF BOTH IMAGES control.

Cross hairs located at each film plane are controlled by the RIGHT FILM CROSS-HAIR joystick and LEFT FILM CROSS-HAIR joystick. Cross-hair position measurements may be obtained from X and Y CROSS-HAIR POSITION meters adjacent to each joystick. The meters read directly in centimeters. A zero reading on all the meters indicates that the cross hairs are centered in the film apertures.

Three focus controls are available in the system. The LEFT LENS FOCUS and RIGHT LENS FOCUS controls are used to adjust the optical focus of the system. The FILM CRT FOCUS control is used to adjust the electronic focus of the scanning cathode ray tube light source. The focus controls should be set after the MAGNIFICATION INCREASE switch has set the magnification to near maximum in order to obtain maximum focus sensitivity. After the system has been allowed to warm-up to its normal operating temperature, further adjustment of these controls is not normally necessary.

Any of four preset frame lengths may be counted by utilizing the FRAME LENGTH SELECTOR switch and FRAME COUNTER associated with each film. In addition, any frame number series may be set into the FRAME COUNTER by rotating the SET control. Films whose frame lengths are not the same may be inserted in the respective film magazines with no loss in counting accuracy. When films having frame lengths longer than the 70 millimeter film aperture width are inserted the FRAME POSITION INDICATOR may be used to measure the distance the film has traveled from a reference point to the area of interest within the viewing aperture. These indicators which read directly in millimeters, when used in conjunction with the cross hairs, allow an area of interest to be measured directly with respect to a reference point. Due to the counting rate limitation of the indicators they only operate when the film advance speed switches are in the SLOW position.

h. Console

The change detector console shown in Figure 20 has been constructed so that it may be separated into three separate units for ease of transportation from one location to another. With the control

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panel and desk top removed, the cabinet containing the registration mechanism can be separated from the display unit. Each of the two large units sets on four casters which allow them to be moved without the aid of a fork lift. When coupled together, steel pins inserted in the base assembly insure exact positioning of the two units. The units are also bolted together at the base joint and between cabinets for added rigidity. Adjustable jack pads are provided to keep the system level regardless of the condition of the supporting floor.

The console has been fabricated to provide complete access to all system components within. The two large doors permit easy access to the film drives for film loading, as well as the complete registration mechanism for servicing or adjustment. The power supply controls and programmer may be reached through the set of doors beneath the control panel. The two display monitors are mounted in slide assemblies for easy removal if servicing is necessary. A hinged control panel allows entrance to the circuitry located beneath the panel. In addition, nearly all of the outside panels on the console are removable.

System cooling is provided by the main system blower located at the lower left end of the registration unit. Filtered air maintains a positive pressure throughout the console to minimize dust. The 415 cubic feet per minute air flow furnished by the blower is equally divided between the registration and display units. Light tight exhaust ventilators are located at either side of the registration unit. The perforated rear panels of the display unit are used for exhaust in that compartment. Local "hot spots", such as the system backlight and control panel electronics, are provided with small fans for improved air circulation.

SECTION IV - SYSTEM PERFORMANCE

1. CHECKOUT AND INSTALLATION

In-plant checkout of the system consisted mainly of a checkout and alignment of the individual system components. Gain and velocity feedback adjustments were performed on each of the servo systems to optimize the response and positional accuracy. Alignment of the optical system consisted of centering the rotation of the dove mirror assembly about the optical axis by adjusting the shim thickness and positioning the autofocus linkages to insure that the mechanism maintained focus over the entire scale factor range. A coarse positioning of the field lens mirror combination was performed to adjust the alignment of the correlation system with the display system. After it was determined that the components of the entire system were

operating within specifications, the system was separated into the three units and was shipped.

Upon arrival, the separate units were reassembled and the system was operated. No problems due to shipping were encountered.

A final alignment of the relative positions of the CRT and field lens mirror was undertaken to obtain exact registration between the correlation and readout systems. Due to the differences in the method of obtaining scale factor corrections between the readout system, which uses the two optical paths singularly, and the correlation system which combines the two optical paths, a determination of the exact point of registration is a time consuming process. The procedure used was as follows: the images were manually aligned as accurately as possible; backlights were activated behind each of the scenes and a ground glass viewing screen was installed in place of the field lens mirror. The superimposed images were then aligned within the resolution limit of the screen by repositioning the screen. Since the registration of the two systems required alignment accuracies beyond the resolution capability of the viewing screen, the mirror was re-inserted at the last position of the viewing screen. From this point, successive operations of the correlation and readout systems, as the mirror was displaced in small increments, resulted in a convergence upon the exact point of alignment.

During the checkout phase, two problems were encountered in the operation of the film drive assemblies. The first was an instability observed in the film tension loop especially at the ends of the film travel. The second was repeated failures in the purchased two-speed gearheads which were installed ahead of the tension control clutches attached to each film spool. The gearhead failures occurred in the slow speed position. The two-speed requirement in the film tension control loop was imposed originally by a mechanical damper which was installed to stabilize the loop. The mechanical dampers were replaced by the magnetic velocity damping mechanism described in the text. This installation eliminated both the stability problem and the need for the two-speed gearheads because of the resultant increased loop stability. The damaged gearheads were removed and re-worked to operate at a single speed. No further problems were encountered.

2. SYSTEM SPECIFICATIONS

Table III shows a list of system specifications which have been determined by personnel in tests performed prior to and after delivery of the system.

TABLE III - SYSTEM SPECIFICATIONS

Film Input Data	
Film	70-mm roll, 250 ft max
Film Aperture Size	70-mm x 70-mm
Film Speed	
Slow Mode	0 - .2 inches/sec
Fast Mode	0 - 24 inches/sec
Frame Counter Accuracy	
Position No. 1 (2.3) in	≦ 5 frames for 250 ft of film
2 (10.45) in	≦ 1 " " " " " "
3 (30) in	≦ 1 " " " " " "
4 (30.7) in	≦ 1 " " " " " "
Image Registration	
Manual X Registration	± 50 percent of aperture for both left and right controls
Manual Y Registration	± 50 percent of aperture for both left and right controls
Manual Rotation	± 180 degrees
Manual Scale Factor	2X
Tip	± 5 degrees
Tilt	+ 5, -3 degrees
Automatic Registration Time	80 sec
Display Data	
Film to Monitor Magnification	5X
Magnification Control Range	40X
Resolution	
Minimum Magnification	Approx. 6 line pairs/mm
Maximum Magnification	Approx. 30 line pairs/mm
Flicker Rate	1/2 to 6 cycles/sec

TABLE III - (Cont'd.)

Cross-Hair Position Accuracy	± 5 percent of film aperture
Physical Data	
Overall Size (including control desk)	80 in high x 105 in long x 45 in deep
Weight	2500 lbs.
Power Requirements	
Primary Power	105 - 125 volts AC at 25 amperes, 60 cycles - single phase

Limited tests using nearly identical aerial imagery have determined that the autocorrelation repeatability is within .1 percent in X,Y, azimuth and scale factor. This was determined by displacing the two scenes in all four degrees of freedom, activating the automatic registration system, and observing the resulting displacements in X, Y and azimuth with the scanning CRT raster set at maximum area blow-up. Since a .1 percent displacement represents approximately .002 inches and 1/3 degree in X and Y and azimuth, respectively, it is easily resolved by the 30 line pair per millimeter readout resolution which allows observation of displacements of approximately .001 inch. Measurements of scale factor repeatability were performed by actual measurement of axial translation of the lens mechanisms. Although the repeatability of autocorrelation of the two films provided a good indication of the registration accuracy, the absolute accuracy was difficult to determine because the available imagery contained small, but significant, amounts of relative distortion and defocusing. Unless

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imagery with dissimilarities beyond the measuring capabilities of the change detector is used, the distortions present contribute heavily to any accuracy measurements.

The manual registration accuracy required to achieve satisfactory X and Y automatic registration is limited primarily by the magnitude of the search function. This amplitude is approximately 15 percent of the film aperture in either axis, which establishes an upper bound on the manual misregistration for most types of imagery. The ability of the correlation system to register residual scale factor and azimuth errors is dependent on the target content of the imagery. Successful correlation of typical aerial imagery containing relative azimuth errors of up to 5 degrees and scale errors between 3 and 5 percent have been achieved, although only limited tests have been performed. Larger errors may require several cycles of the automatic registration sequence if the three iteration cycles do not completely null the error.

3. PROBLEM AREAS

A comparison of the system specifications with the original design goals shows that most have been met or exceeded by the system. One problem area exists, however, in the readout resolution. A previous discussion has indicated that the resolution limit is primarily due to the selection of a scanning CRT which is a compromise between the light level and resolution requirements of the system. In addition, the high voltage power supply designed for use in the system

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was built for use with a different CRT employing lower anode voltage. As a result, the performance of the CRT is not optimum for either resolution or light output. Under a separate maintenance program a power supply has been purchased which will generate voltages up to 25 kilovolts. An improvement in both readout resolution and light output is anticipated when this supply is installed.

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